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Source Test and Evaluation Report
Stoic Low-BTU Gasifier

Radian Corp., Austin, TX

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ENVIRONMENTAL ASSESSMENT: SOURCE TEST AND EVALUATION REPORT-- STOIC LOW-BTU GASIFIER

by

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Coal Gasification	Electrostatic Precipitators	Stoic Process	13H	
Combustion			21B	13I
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ABSTRACT

Under contract to the Environmental Protection Agency, Radian Corporation performed a Source Test and Evaluation of the Foster Wheeler/Stoic gasifier located at the University of Minnesota-Duluth Campus (UMD). The test, which ran from February 23 to March 6, was designed to collect data pertinent to an environmental assessment of the Foster Wheeler/Stoic two-stage gasification process, including evaluation of the emissions from the combustion of both the product gas and the by-product ESP oil. Results of the test are presented in this report.

Distribution of minor and trace elements in the product, by-product, and discharge streams were calculated from elemental mass flow rates. Evaluation of elemental behavior was also performed by comparing the concentration of an element in a stream to the concentration of the element in the ash mineral fraction of that stream.

Extractable organic material in product gas, by-product ESP oil, and discharge streams was characterized by total organic loading and by gas chromatographic analysis. Priority pollutants were identified and quantitated for major streams. The gas clean-up devices (ESP and cyclone) were evaluated for both efficiency and effects on the gas composition.

Evaluation of test results indicated that combustion of ESP oil and product gas destroyed priority organic pollutants to the extent that less than one percent of the original levels was detected. Also, most of the hydrocarbons (C1-C6) present in the combined product gas were destroyed by combustion.

Although federal New Source Performance Standards (NSPS) do not apply to the Foster Wheeler/Stoic gasifier boilers because of their size, if these standards were applied, SO_2 emissions would fall slightly above or slightly below NSPS levels, depending on the method of calculation. NO_x emissions would be marginally above NSPS, and emission levels of particulates would fall well below NSPS.

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SECTION 1
INTRODUCTION AND SUMMARY

Radian Corporation is under contract to the Environmental Protection Agency (EPA) to perform a comprehensive assessment of low- and medium-Btu coal gasification technology. The program includes the performance of Source Tests and Evaluations to gather data for the assessment of commercially-viable low- and medium-Btu coal gasification systems.

This Source Test and Evaluation Report (STER) presents the findings of a limited environmental assessment of the Foster Wheeler/Stoic two-stage gasifier. The Foster Wheeler/Stoic two-stage gasifier was developed by Stoic Combustion (Pty.) Limited of Johannesburg, South Africa and is marketed by Foster Wheeler Energy Corporation, with licensing rights in North and South America, Europe, Asia, and Australia.

The University of Minnesota, with funding from the Department of Energy's (DOE) "Gasifiers in Industry" Program, constructed and now operates a Foster Wheeler/Stoic two-stage gasifier on the University of Minnesota-Duluth (UMD) campus. The test program was conducted during February and March, 1981 as part of a joint field test effort between Oak Ridge National Laboratories (ORNL) and EPA. Personnel from the Lake Superior Basin Studies Center (LSBSC), a research arm of UMD, assisted during the test, contributing to both the ORNL and EPA programs.

1.1 Test Overview

The source test was designed to collect data pertinent to the environmental assessment of the Foster Wheeler/Stoic two-stage gasifier. Testing was conducted from February 23 to March 6, 1981 under "steady-state"

operating conditions. During the 12-day test period, approximately 280 metric tons of bituminous coal were gasified at an average rate (including standby periods) of 270 g/s (2140 lb/hr). Samples of major process and discharge streams, including gaseous discharge streams from boilers combusting the product gas and by-product oil removed from the product gas stream by an electrostatic precipitator (ESP), were characterized. The selection of streams for testing was made based upon the stated program objectives:

- Performance of an environmental assessment of the Foster Wheeler/ Stoic two-stage gasification process including the gaseous discharge streams resulting from combustion of the product gas and by-product ESP oil.
- Calculation of material balances around the plant systems.
- Evaluation of the emissions from combustion of the product gas, as related to the product gas composition.
- Evaluation of the emissions from combustion of the ESP oil, as related to the ESP oil composition.
- Evaluation of the efficiency of product gas clean-up systems (ESP and cyclone) and their effect upon gas composition.

1.2 Results

This section summarizes the results obtained and evaluation made in this report. The areas include:

- process flow rates and material and component balances,
- elemental behavior,
- extractable organics,
- gas composition,
- efficiency of gas clean-up devices,
- water quality, and
- leaching studies.

1.2.1 Material and Component Balances

Material and component balances around the gasifier closed within 3 to 14 percent. Carbon and sulfur displayed the greatest difference between mass out and mass in. The overall material balance and flows normalized to coal flow per ton are presented in Table 1.

The gasifier had a cold gas efficiency* of approximately 80 percent during the test period. However, this value should not be taken as representative of this gasifier's typical performance. This calculated efficiency is not supported by a detailed energy balance since heat balance and efficiency calculations were not within the scope of work.

Material and component balances around the product gas boilers closed within 10 to 50 percent. Hydrogen, which included gravimetrically determined moisture in the combustion gases, exhibited the poorest balance, with an out/in ratio of 1.5. Sulfur also exhibited poor closure around the product gas boilers, with an out/in ratio of 1.3.

Material and component balances around the boiler firing ESP oils indicate closure within 4 to 10 percent for all species except sulfur, which showed an out/in ratio of 1.6.

1.2.2 Elemental Behavior

<u>Distribution</u>

Of the 65 elements for which analytical data allowed an evaluation of elemental behavior, 57 are found in the gasifier ash and 43 of these have 95

*Cold gas efficiency is a measure of the ability of a gasifier to convert potential combustion energy in coal to potential combustion energy in dry, tar-free product gas.

TABLE 1. OVERALL MATERIAL BALANCE OF FOSTER WHEELER/STOIC TWO-STAGE GASIFIER (UMD)

	Mass Flow Rate* (g/s)	Flow Rate (per ton dry coal)	Flow Rate (per Mg dry coal)
Inlet Streams			
Coal (dry basis)†	270	1.0 ton	1.0 Mg
Moisture in coal#	30	--	--
Ash pan water make-up	7	52 lb	24 kg
Blast air (with steam)	690	71,300 scf	1,870 Nm^3
Purge steam	22	163 lb	74 kg
TOTAL IN	1,019		
Outlet Streams			
Gasifier ash	44	0.162 tons	147 kg
Cyclone dust	0.2	1.48 lb	0.67 kg
ESP oil**	4	0.093 bbl	0.015 m^3
Combined product gas††	1,005	121,000 scf	3,180 Nm^3
TOTAL OUT	1,053.2		

*From Table 10.
†Ultimate analysis: C = 69.88%
H = 4.53%
N = 1.45%
S = 0.52%
Ash = 9.51%
O = 14.11 (by difference)
Btu/lb = 12,012 (2.7E7 J/kg)
#Moisture content taken as 10%.
**HHV of ESP oil is 18,930 Btu/lb (4.4E7 J/kg).
††HHV of combined product gas is 158 Btu/scf (6.3E6 J/Nm^3).

percent or more of their mass discharged in the gasifier ash. Five elements (antimony, bromine, chlorine, sulfur, and tin) have significantly more than 25 percent of their total mass in the combined product gas stream and may be considered to exhibit volatile behavior.

While bismuth, lead, and zinc are discharged primarily in the gasifier ash, 30 to 45 percent of the total mass discharged is found in the cyclone dust, ESP oil, and product gas. Tin, mentioned above as having more than 25 percent of its discharged mass in the product gas stream, is actually distributed almost equally across the bottom ash, cyclone dust, and product gas.

Enrichment

Another approach to evaluation of elemental behavior in the gasification process is the use of elemental concentration quotients. A concentration quotient is defined here as the ratio of the concentration of an element in a specific stream to the concentration of that same element in the feed coal.

Elements enter the gasifier in the feed coal and are concentrated in the ash minerals as the carbonaceous materials and many of the volatile components react to form the gaseous products of gasification. If elemental enrichment is due to nothing more than the concentration of elements in the resulting ash mineral fraction, then the change in elemental concentration would be equal to the change in concentration of ash mineral fraction in a stream. However, due to various chemical or physical characteristics, a number of elements exhibit changes in concentration that are different from that of the ash mineral fraction (i.e., their concentration quotients are greater or smaller than the concentration quotients calculated for the ash mineral fraction). If their concentration quotient is greater than that for ash mineral fraction, they are considered to be enriched in the stream with respect to ash mineral fraction. Conversely, if their concentration quotient is smaller, they are considered to be depleted with respect to ash mineral fraction.

Most of the elements are discharged primarily in the gasifier bottom ash. Fourteen elements which were found in the gasifier bottom ash had not been found at detectable levels in the feed coal. These were:

Bismuth	Hafnium	Thallium
Dysprosium	Holmium	Thulium
Erbium	Lutetium	Tungsten
Europium	Tantalum	Ytterbium
Gadolinium	Terbium	

Eleven elements detected in the coal were found to be enriched with respect to ash mineral fraction. These were:

Arsenic	Fluorine	Manganese
Boron	Iron	Neodynium
Calcium	Lanthanum	Rubidium
Cesium	Magnesium	

Four others, cerium, niobium, potassium, and sodium, show concentration quotients only slightly higher than the concentration quotient for the ash mineral fraction, indicating neither enrichment nor depletion. The other elements found in the gasifier bottom ash were depleted with respect to the ash mineral fraction (see Table 2).

Ten elements were found in the cyclone dust which were not found at detectable levels in the coal. These were:

Bismuth	Gadolinium	Terbium
Dysprosium	Hafnium	Thallium
Erbium	Holmium	Tungsten
Europium		

Ten elements detected in the coal were found to be enriched in the cyclone dust with respect to ash mineral fraction. These were:

Antimony	Germanium	Mercury
Arsenic	Iodine	Tin
Fluorine	Lead	Zinc
Gallium		

TABLE 2. CONCENTRATION QUOTIENTS OF ELEMENTS AND ASH MINERALS IN GASIFIER ASH, CYCLONE DUST AND ESP OIL

Element	Concentration Quotient*			Element	Concentration Quotient*		
	Gasifier Ash	Cyclone Dust	ESP Oil		Gasifier Ash	Cyclone Dust	ESP Oil
Aluminum	6	2	<0.01	Neodymium	21	2.2	--
Antimony	1	95	1	Nickel	6.7	3.5	0.2
Arsenic	13	17	0.45	Niobium	9.5	2.5	--
Barium	6.9	0.7	0.01	Osmium	--	--	--
Beryllium	3	2.7	--**	Palladium	--	--	--
Bismuth	0.5	20	0.2	Phosphorus	1	1	<0.01
Boron	28	4	0.04	Platinum	--	--	--
Bromine	1.5	3.5	0.05	Potassium	8.6	2.8	0.03
Cadmium	5	3	--	Praseodymium	8	2.5	<0.01
Calcium	15	3.6	<0.01	Rhenium	--	--	--
Cerium	9	2.5	<0.01	Rhodium	--	--	--
Cesium	27	2.3	--	Rubidium	15	2.2	<0.01
Chlorine	0.37	3.2	0.01	Ruthenium	--	--	--
Chromium	8	3.8	0.02	Samarium	3	2	--
Cobalt	7.5	2.7	0.4	Scandium	2	1	<0.01
Copper	6.6	4.6	0.03	Selenium	1.7	7.2	0.8
Dysprosium	30	20	--	Silicon	1	1	<0.01
Erbium	15	4	--	Silver	0.4	2.5	0.25
Europium	5	5	--	Sodium	8.3	3.8	0.27
Fluorine	16	>143	0.6	Strontium	1	0.8	<0.01
Gadolinium	20	10	--	Sulfur	0.53	1.9	0.46
Gallium	4.6	56	0.01	Tantalum	3	--	--
Germanium	3.5	95	0.1	Tellurium	0.5	2.5	--
Gold	--	--	--	Terbium	5	4	--
Hafnium	10	10	--	Thallium	2	60	--
Holmium	20	5	--	Thorium	7.3	2	--
Iodine	1	10	0.15	Thulium	1	--	--
Iridium	--	--	--	Tin	1.2	192	0.1
Iron	11	3.3	0.05	Titanium	4.1	1.8	<0.01
Lanthanum	20	2.2	<0.01	Tungsten	10	20	--
Lead	4	290	0.13	Uranium	6.3	2.3	--
Lithium	5.3	2.3	<0.01	Vanadium	6.8	2.5	0.27
Lutetium	1.5	--	--	Ytterbium	10	--	--
Magnesium	16	3.2	<0.01	Yttrium	3.6	1.1	--
Manganese	18	2	0.02	Zinc	2.9	121	0.14
Mercury	4.3	10.7	2.3	Zirconium	6.4	1.8	<0.01
Molybdenum	5.5	2.6	0.2	Ash Minerals	8.2	2.8	0.02

$$\text{*Concentration quotient} = \frac{\mu g \text{ element/g stream}}{\mu g \text{ element/g coal}} \text{ or } \frac{\mu g \text{ ash minerals/g stream}}{\mu g \text{ ash minerals/g coal}}$$

**Element not detected in stream.

Thirteen elements were found at levels equal to or only slightly higher than the ash mineral fraction. These were:

Boron	Chromium	Nickel
Bromine	Copper	Potassium
Cadmium	Iron	Selenium
Calcium	Magnesium	Sodium
Chlorine		

The rest of the elements found in the cyclone dust were depleted in respect to ash mineral fraction (see Table 2).

While a number of elements appeared to be enriched with respect to the ash mineral fraction of the ESP oil (which was quite low), only mercury was present at a concentration (mass/mass) exceeding its concentration in the feed coal. The concentration of antimony in the ESP oil was essentially identical with its concentration in the feed coal, and the concentration of selenium was within 20 percent of its concentration in the feed coal. All other elements in the ESP oil were found at concentrations significantly lower than their concentrations in the feed coal.

1.2.3 Extractable Organics

The majority of the extractable organic materials leaving the gasification process are found in the ESP oil and product gas streams and are combusted in the boilers. The largest amount of priority pollutants leaving the gasifier were found in the ESP oil. However, combustion of the ESP oil was effective in destroying the priority pollutant load. Less than one percent of the priority pollutant load in the ESP oils was found in the emissions from combustion of the ESP oil. Though the priority pollutant loading in the product gas was lower than in the ESP oil, combustion was likewise an effective means of destruction. Less than one percent of the priority pollutants identified in the product gas was detected in the combustion emissions.

Few polynuclear aromatics (PNAs) were detected in the product or emissions streams. Notably absent were acenaphthalene, benzo(a)pyrene, and fluoranthene.

1.2.4 Gas Compositions

The majority of the hydrocarbons (up to C_6) present in the combined product gas were destroyed upon combustion in the product gas boiler. The mass flow rate for C_6 hydrocarbons appeared to be higher in the boiler emissions than in the product gas stream. However, the difference was small and, based upon the standard deviation in the analytical results, no absolute difference can be concluded.

There was no change in the gas composition for the top product gases as a result of the gas clean-up, except for the concentration of aerosolized components. Because of process variations at the time the bottom gases were analyzed, no conclusions were drawn regarding the effect of the cyclone on the composition of the bottom gas.

The majority of gas phase organics exits the gasification process in the top gas. The mass flow of C_1-C_6 hydrocarbons in the treated top gas is about two orders of magnitude higher than in the treated bottom gas.

1.2.5 Efficiency of the Gas Clean-up Devices

The collection efficiency of the ESP used to remove aerosolized oils and particulate matter from the top product gas was found to be approximately 98 percent for oils and 72-74 percent for particulate matter. The collection efficiency for the cyclone was not evaluated because of difficulties in determining a consistent gas flow at the sampling point.

1.2.6 Water Quality

Ash pan water losses occur because of evaporation and carryover with the gasifier ash. Ash pan water may enter the environment as residual drainage from the gasifier ash while it is stored prior to disposal. Water quality analyses were performed on the ash pan water to determine its pollution potential if it should be discharged directly into the environment.

Concentrations of barium (1.5E3 μg/L) and mercury (4.2 μg/L) in the ash pan water exceed permissible levels set in the National Interim Primary Drinking Water Standards (1.0E3 μg/L Ba and 2 μg/L Hg). The presence of mercury, however, may be an artifact of a mercury spill in the ash pan during an early period of operation of the gasifier.

The pH of the ash pan water (12.5) is significantly higher than the range specified (6.5-8.5) in the National Secondary Drinking Water Standards (NSDWS). Total dissolved solids, at 1.8E6 μg/L, exceeds the NSDWS level of 5.0E5 μg/L.

The reader should remain aware that the comparisons made above are between process wastewater and drinking water standards, and that the impact of the concentrations observed for barium, mercury, pH, and TDS would be diminished by dilution of the discharge stream in receiving waters as well as by other factors specific to a given site.

1.2.7 Leachates

Elemental materials in gasifier ash or cyclone dust may enter the environment as a result of leaching by ground or run-off waters from a disposal site. Leaching studies provide a measure of the potential for release of contaminants to the environment.

According to the results of analyses performed on leachate from gasifier ash and cyclone dust, these streams can be considered as non-hazardous

solid wastes under RCRA criteria. None of the components found in the extracts appeared at levels greater than ten percent of their maximum allowable concentration.

SECTION 2
PLANT DESCRIPTION

The University of Minnesota, with funding from the Department of Energy's "Gasifiers in Industry" Program, constructed and now operates a Foster Wheeler/Stoic two-stage fixed bed gasifier on the University of Minnesota-Duluth (UMD) Campus. The University of Minnesota selected a Foster Wheeler/Stoic two-stage gasifier because it has a higher capacity than many other gasifiers, enabling one gasifier to supply sufficient product gas to satisfy the heating needs of the campus. In addition, by concentrating the by-product oil in the top gas stream, by-product oil recovery may be accomplished with an electrostatic precipitator (ESP) which is approximately half the size of one that would be required for a single-stage gasifier of the same capacity. The by-product oil can be collected, stored, and burned during peak heating requirements or during periods of very low energy consumption when operation of the gasifier is not economical.

The UMD campus heating plant operates three boilers having a total capacity of 45 Mg (100,000 pounds) of steam per hour. Two of the boilers have been retrofitted to fire either low-Btu product gas or fuel oil. The third boiler is capable of firing the by-product oils from the gasification process, as well as fuel oil or natural gas. The gasification facility is annexed to the existing heating plant on the UMD campus and, along with the coal delivery and solid waste disposal areas, is entirely enclosed.

2.1 Gasification Process

2.1.1 Gasification Process Description

The Foster Wheeler/Stoic two-stage gasifier was developed by Stoic Combustion (Pty.) Limited of Johannesburg, South Africa and is marketed by

Foster Wheeler Energy Corporation, with licensing rights in North and South America, Europe, Asia, and Australia. The gasifier is an atmospheric pressure, air-blown, fixed bed gasifier that produces a low-Btu product gas having a lower heating value of approximately 5.6E6 J/Nm^3 (150 Btu/scf). The unit has a diameter of approximately 3 m (10 ft.). The added height, in relation to single-stage units, serves to increase gas residence time and improve volatiles distillation properties of the reactor. The design throughput of the gasifier is 2.7 Mg (3 tons) of coal per hour. At this feed rate, the gasifier provides sufficient product gas to produce about 20 Mg (44,000 pounds) of steam per hour. The unit is capable of operating at pressures of 7.5 kPa (30 inches of water), which increases the delivery pressure of the product gas and minimizes problems associated with combustion burner selection and control.

Sized coal is fed to the gasifier through the top of the unit and blast air, saturated with H_2O, enters through the bottom. Product gas is removed from the reactor in two locations. One stream, known as top product gas, is withdrawn through the top of the reactor. Another stream, known as bottom product gas, is removed from above the reaction zone in the lower area of the reactor.

There are three zones of activity in fixed-bed gasification processes: oxidation, reaction, and volatilization. The oxidation zone exists just above the ash bed, is only inches thick, and is the first zone in the reactor to contact the oxygen in the blast air. In the oxidation zone, a portion of the carbon in the coal is combusted, exhausting the oxygen available in the blast air, and producing heat for subsequent gasification reactions. Above the oxidation zone is the reaction zone where the reactor atmosphere becomes reductive. Carbon monoxide and hydrogen are produced primarily by the reaction of carbon in the coal with water provided by the saturated blast air. The volatilization zone is in the upper part of the gasifier. Here, the hot product gases meet the unreacted incoming coal, causing volatilization of coal hydrocarbons and evaporation of moisture.

In two-stage gasification, the removal of a portion of the product gases near the reaction zone serves to regulate the heat available in the volatilization zone in the upper part of the gasifier. As a result, the incoming coal is heated slowly, causing the volatile hydrocarbons to distill without cracking and with minimal polymerization. The majority of the volatile hydrocarbons are carried from the gasifier in the top gas stream, from which they can be condensed and collected as a by-product. The by-product oil is relatively viscous, but can be used as a liquid fuel. An additional feature of two-stage gasification is that collection and removal of the aerosolized oil is more efficient since it is borne in only approximately one-half of the product gas volume (the top gas).

The particulate concentration in the top product gas may be less than particulate concentrations in single-stage units due to the lower space velocity through the bed. Therefore, oils collected from the top product gas are relatively free of particulate matter.

The combustible components in the bottom gas are primarily carbon monoxide and hydrogen. The bottom product gas contains less oil and more particulate matter than the top product gas. Particulates are removed from the bottom gas by a refractory-lined hot cyclone. The collected particulates are removed from the cyclone by a lockhopper system. The cyclone dust is stored and shipped in drums for disposal.

2.1.2 UMD Facility Description

Figure 1 shows a schematic of the UMD gasification facility. The top product gas is passed through an electrostatic precipitator (ESP) where the aerosolized oils and any particulate matter are collected. The oil flows by gravity from the ESP into an underground heated storage tank where it is stored for future use. The ESP oil is similar to No. 6 fuel oil and has a heating value of about 4.3E7 J/kg (18,700 Btu/lb). The cleaned top product gas has a lower heating value of about 6.2E6 J/Nm^3 (170 Btu/scf) and the cleaned bottom gas has a lower heating value of approximately 4.8E6 J/Nm^3 (130 Btu/scf).

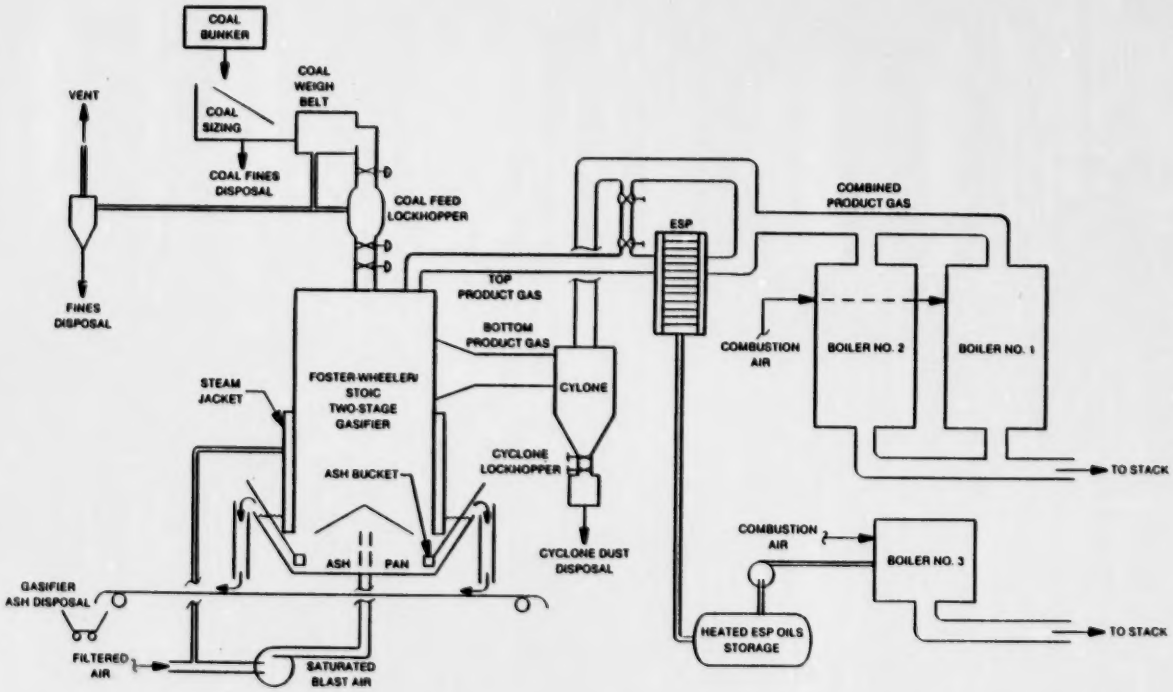


Figure 1. A schematic illustration of the Foster Wheeler/Stoic two-stage gasifier at the University of Minnesota-Duluth campus.

The bituminous feed coal used during the test program was mined from the Pinnacle Seam by Sun Coal Co., Milner, Colorado. Due primarily to the moisture content of the feed coal, the temperature of top product gas was lower than the engineering design value of 120°C (250°F). At this lower temperature, plant officials were concerned that water might condense from the top product gas stream and short out the ESP. A cross-over line was constructed between the bottom product gas line downstream of the cyclone and the top product gas line upstream of the ESP. This permitted the injection of hot, treated bottom gas into the raw top gas stream. Flow in the cross-over line was adjusted manually as necessary to maintain a top product gas temperature of approximately 95°C (200°F). The amount of bottom gas injected into the top gas line upstream of the ESP was not monitored and is, therefore, difficult to assess.

The cleaned top product gas (downstream of the ESP) and the remainder of the cleaned bottom gas (downstream of the cyclone) are combined to form the combined product gas. The temperature of the combined product gas is sufficiently high to maintain all condensable oils as vapors, preventing fouling in downstream gas lines or in the product gas burners. At the UMD facility, the entire production of combined product gas is burned in two boilers, producing steam that is used to heat the campus buildings.

The ash produced by the process is collected in a water-filled ash pan below the gasifier, which also forms a water seal for the gasifier. The depth of the water in the ash pan is a major factor establishing the allowable maximum operating pressure. The ash pan rotates constantly and forces ash into buckets situated at the bottom of the ash pan. The hydraulically operated buckets (two at 180° to each other) lift the ash from the ash pan and drop the ash onto a belt conveyor which transfers the ash to a storage location prior to disposal. Water drains through metal screens in the bottoms of the buckets. The buckets withdraw ash automatically, on a timed sequence.

The system requires make-up water for maintenance of the ash pan water level and for production of steam for the blast air. Water losses from the ash pan are due to evaporation and carryover with gasifier ash.

Coal sized from 1.3 cm to 5 cm (1/2 in. to 2 in.) is delivered to the plant in trucks and transported by conveyor into storage hoppers. From the storage hoppers, the coal is transported to a coal feed bunker which delivers the coal to a screening operation where fines are removed. The coal then passes to a weigh belt which feeds the coal into a lockhopper above the gasifier. The lockhopper reduces emissions to the work area by maintaining a seal on the gasifier during the coal feed operation. The lockhopper has two automatic sliding gate valves below the hopper and one automatic sliding gate valve above the hopper. The valve operation sequence is as follows: the valve above the lockhopper opens to fill the lockhopper with coal and then closes; the lowermost valve below the lockhopper opens followed by the other valve below the lockhopper, thus dropping the coal into the gasifier; both valves below the lockhopper then close and the cycle is repeated. The operating sequence of the two valves below the lockhopper keeps the weight of the coal from affecting the seal between the gasifier and lockhopper. Each dump of the lockhopper feeds about 45 kg (100 lb) of coal to the gasifier.

2.1.3 Plant Operation

The testing described in this source test and evaluation report was conducted February 23 through 27 and March 2 through 6, 1981. Gasifier operation during the week of February 23 was consistent, with an average coal feed rate of 310 g/s (1.25 tons/hr). On the morning of February 25, there was a minor plant disturbance caused by a malfunction in a valve on Boiler No. 1. The gasifier was turned down briefly to allow for repairs on the boiler valve, but was once again operating smoothly within a few hours after the repairs had been completed.

On March 2, the gasifier was shut down due to pressure drop inconsistencies across the bed, which were presumed to have resulted from an increased level of fines in the coal feedstock. Plant personnel made use of this down time to perform routine maintenance on the gasifier (primarily cleaning hardware systems). The gasifier resumed operation about midday on March 4, on coke. Sampling of the process began about midday on March 5 when the gasifier was again operating on coal, and all of the coke had passed through the oxidation zone. During this sampling period, the average coal feed rate was 330 g/s (1.3 tons/hr).

2.2 Heating Plant

2.2.1 Facility Description

The UMD campus heating plant has three boilers available for production of steam used to heat campus buildings. As part of the program to install the gasifier, two of the boilers (Boilers No. 1 and 2) were retrofitted to fire the low-Btu product gas. The retrofit reduced the maximum steam output of the two boilers from 11.3 to 10.9 Mg (25,000 to 24,000 pounds) of steam per hour. The two boilers, manufactured by Keeler, are capable of firing fuel oil in addition to the low-Btu product gas. The combustion emissions of the two boilers are combined and exhausted through a stack approximately 30 meters (100 feet) high.

Boiler No. 3, manufactured by Combustion Engineering, has a capacity of 22.7 Mg (50,000 pounds) of steam per hour and can be fired with ESP oil, fuel oil, or natural gas. The emissions of Boiler No. 3 are exhausted through a stack extending about 3 meters (10 feet) above the roof of the heating plant.

2.2.2 Plant Operation

During the period when combustion emissions from the product gas boilers were sampled (February 24 and 25), the boilers were operating smoothly at about 75% capacity. The combustion emissions of Boiler No. 3 burning ESP

oil were sampled March 2 and 3 when the boiler was operating at about 25% capacity. The combustion emissions from Boiler No. 3 were also sampled March 4 during firing of natural gas.

SECTION 3
SAMPLING

This section describes the joint sampling effort by Radian and Oak Ridge National Laboratories which was conducted February 23 through 27 and March 2 through 6, 1981. The sampling schedule and brief discussions of the technical approach of this project and the techniques used for collection of samples during the field effort are also presented. More detailed descriptions of the sampling techniques are presented in Appendix C.

3.1 EPA/ORNL Joint Effort

Oak Ridge National Laboratories (ORNL) has been conducting a multi-year program to assess environmental and health effects associated with the Foster Wheeler/Stoic gasifier at UMD. Personnel at the Lake Superior Basin Studies Center (LSBSC), a research arm of UMD, have performed environmental on-site sampling and analysis under contract to ORNL.

Discussion between EPA and ORNL prior to the planned test indicated that the scopes of both the ORNL and EPA programs were similar and could be performed more efficiently by conducting a joint field effort. ORNL possesses a full compliment of hardware necessary for sampling the diverse types of gas streams at the gasifier. ORNL agreed to contribute the use of the sampling hardware, which had been designed and fabricated by Radian under a previous ORNL contract. EPA agreed to fund some of the analyses of mutual interest as well as all technical support by Radian during the field effort. LSBSC personnel contributed to both the EPA and ORNL sampling tasks.

The joint effort was developed so that alternate days were used for either ORNL or EPA sampling objectives. In general, the personnel on-site jointly performed basically the same tasks for the sampling efforts during both the ORNL and EPA programs. However, personnel on the ORNL and EPA project teams collected solid and liquid samples separately for their respective programs. Also, on-site analyses (gas phase constituents by gas chromatography and wet chemical analyses) were performed only by personnel associated with the respective ORNL or EPA programs. EPA samples for quantitation of trace organics and trace elements in the two combustion emission streams were collected using the source assessment sampling system (SASS) designed by EPA for Level I assessment (1). ORNL collected samples from these streams using a different sampling system.

3.1.1 Schedule

Alternate days were designated for collection of samples for either the ORNL or EPA program. However, the scope of the alternate days' sampling efforts were similar. The sampling objectives were achieved by collecting samples from the following stream pairs on separate days:

- combined product gas and emissions from product gas boilers,
- cleaned top product gas and raw top product gas,
- cleaned bottom product gas and raw bottom product gas, and
- emissions from Boiler No. 3 firing ESP oil and ESP oil to Boiler No. 3.

The emissions from Boiler No. 3 firing natural gas were sampled on a separate day and were not paired with any other stream.

The schedule of sampling conducted by ORNL and EPA is presented in Table 3. In addition to the sampling indicated in Table 3, grab samples for

TABLE 3. EPA AND ORNL SAMPLING SCHEDULE FOR THE UMD GASIFICATION FACILITY

Stream	Feb. 24	Feb. 25	Feb. 26	Feb. 27	March 2	March 3	March 4	March 5	March 6
Combined Product Gas	E* + O	E							
Emissions from Product Gas Boilers	O	E							
Cleaned Top Product Gas			O	E					
Raw Top Product Gas			O	E					
Cleaned Bottom Product Gas								E	O
Raw Bottom Product Gas								E	O
Emissions from Boiler No. 3 Firing ESP Oils					O	E			
ESP Oils to Boiler No. 3					E + O	E			
Emissions from Boiler No. 3 Firing Natural Gas							E		
Coal	E + O	E	E + O	E				E	O
Gasifier Ash	E + O	E	E + O	E				E	O
Cyclone Dust	E + O	E	E + O	E				E	O
ESP Oils to Storage	E + O	E	E + O	E				E	O
Ash Pan Water	E + O	E	E + O	E				E	O

E = EPA Sampling
O = ORNL Sampling
*Ammonia and cyanide only

gas phase analyses (fixed gas, sulfur species, and hydrocarbons) were taken by the EPA team concurrently with the ORNL gas sampling on most days.

3.2 Gasification - Gaseous Process Streams Sampling

Samples of five gaseous process streams were collected during the sampling and analysis effort. The combined product gas was sampled to characterize the fuel to Boilers No. 1 and No. 2. The top product gas and bottom product gas were sampled to evaluate the two clean-up devices (electrostatic precipitator and cyclone, respectively) and to determine if the clean-up devices had an effect upon gas composition. The gas streams entering and exiting the clean-up devices were sampled on the same day, but not concurrently. Following are descriptions of the locations and techniques used to collect samples from each stream.

3.2.1 Sampling Locations

Figure 2 is a schematic of the gasifier and combustion facilities showing the sampling locations for all sampled streams. The five gaseous process streams sampled were:

- combined product gas,
- raw top product gas,
- cleaned top product gas,
- raw bottom product gas, and
- cleaned bottom product gas.

Combined Product Gas

The combined product gas is transported to the product gas boilers in 24-inch pipe. The sampling location is in the mid-section of a 3 m vertical run of pipe. On either end of the vertical run of pipe are elbows, mounted perpendicular with respect to each other. One 4-inch gate valve is mounted about midway between the two elbows, perpendicular to the upstream elbow.

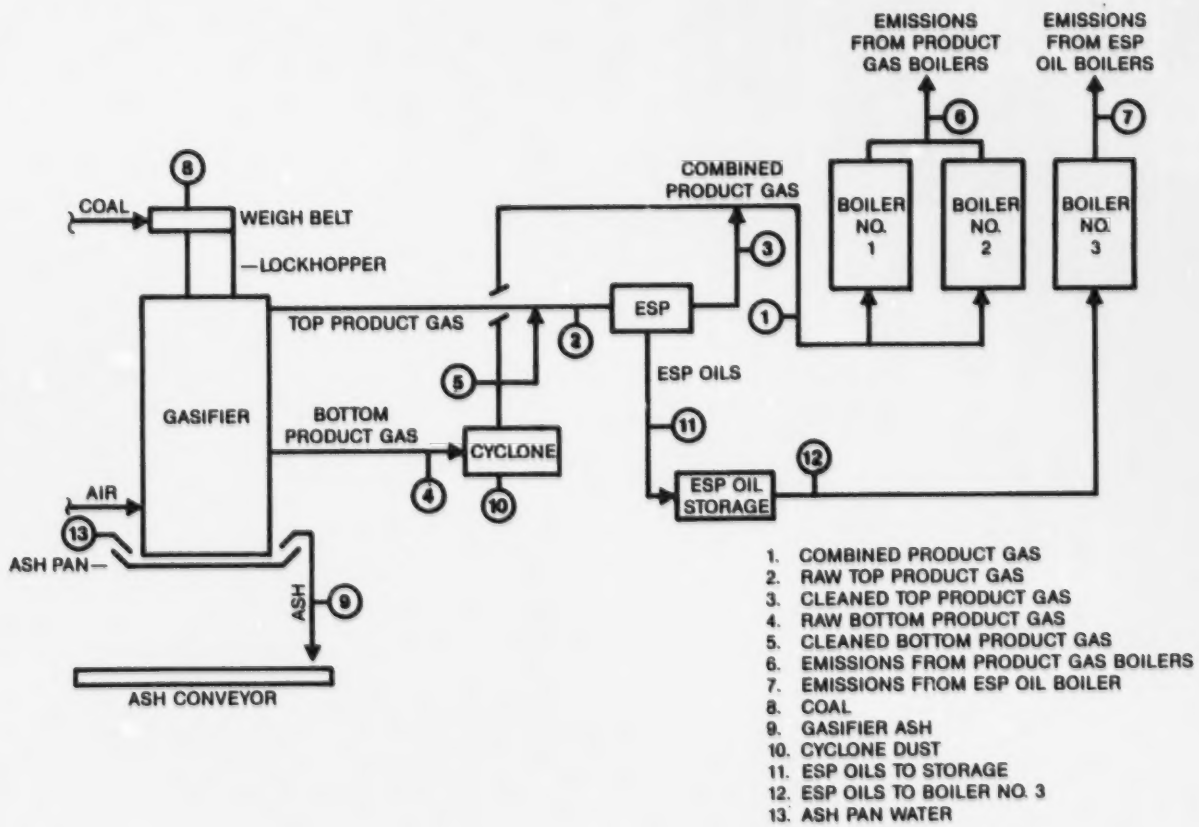


Figure 2. The location of sampling points at the Foster Wheeler/Stoic two-stage gasifier at UMD.

Collection of representative samples of aerosol material in the combined gas may have been hampered by the location of the sampling valve. Particles carried in a gas stream can be concentrated by inertia in the portion of the pipe away from the elbow, thus skewing the particle concentration distribution. Because of the single sampling port and its location, no definition of particle distribution in the stream could be made.

Grab samples for the analysis of major gases, hydrocarbons, and sulfur species by gas chromatography were collected through a 2-inch gate valve mounted near the 4-inch valve.

Raw Top Product Gas

As discussed in Section 2, a portion of the cleaned bottom product gas is combined with the raw top product gas to maintain the temperature of the top gas above the dewpoint. The sampling location for the raw top product gas is about 1 m downstream of the bottom gas injection point. Therefore, the composition of both the raw and cleaned top gas is diluted with cleaned bottom gas. The amount of bottom gas injected into the top gas could not be measured.

One 4-inch gate valve is mounted in a horizontal run of 14-inch pipe about 4 m from an elbow mounted at the gasifier. The injection of the bottom product gas into the raw top product gas line probably disrupts laminar flow patterns at the sampling location. However, because only a single traverse could be performed, no definition of the disruption of the flow could be made.

Grab samples for analysis of major gases, hydrocarbons, and sulfur species by gas chromatography were collected through a 2-inch gate valve mounted near the 4-inch valve.

Cleaned Top Product Gas

The cleaned top product gas exits the electrostatic precipitator (ESP) in a horizontal 16-inch pipe which elbows upward for about 4 m and then elbows once again. The sampling location is about midway between the two elbows. Only one 4-inch sampling valve is mounted in the line, and the valve is not aligned with either of the elbows. Representative samples of aerosols in the cleaned top product gas may not have been collected because of the sampling valve location.

Grab samples for analysis by gas chromatography were collected through a 2-inch gate valve mounted near the 4-inch valve.

Raw Bottom Product Gas

Bottom gas flows from the gasifier to the cyclone in a 2.4 m length of tapered, refractory-lined, rectangular duct. Two 4-inch gate valves are mounted on the duct (one on the side and one on the bottom) about midway between the gasifier and cyclone. Only the valve on the side of the duct could be used for sampling because of physical and process operational restrictions on the bottom valve.

Grab samples for analysis of major gases, hydrocarbons, and sulfur species by gas chromatography were collected through a tee in the gas transport line at the probe exit.

Cleaned Bottom Product Gas

Bottom gas exits the cyclone vertically in a 42-inch refractory-lined pipe. A butterfly flow control valve is located in this section of pipe. Two 4-inch gate valves are mounted horizontally to the pipe, 90° with respect to each other, approximately 30 cm upstream of the butterfly valve. While the butterfly valve does not mechanically or physically interfere with sampling, it probably disrupts flow patterns which may have negatively affected the collection of representative samples.

Only one of the 4-inch valves could be used for probe sampling purposes. The other valve, located at the end of a short horizontal section of pipe which contains a tee to the top product gas, was used to collect grab samples for analysis of major gases, hydrocarbons, and sulfur species by gas chromatography.

3.2.2 Sampling Techniques

Two-stage gasification produces gaseous streams having a wide variation in physical characteristics and requiring different devices and procedures for collection of samples. Typical characteristics of the five sampled process gas streams are presented in Table 4.

All process gas streams are pressurized and contain toxic, flammable gases. Samples from these gas streams must be collected without creating serious health or safety hazards to the personnel in the area. Devices for collection of samples from such streams must be pressure sealed using a packing gland which affixes to a sampling access valve in the process gas line. A sampling probe can then be safely and easily inserted and moved during the sampling process.

Process streams having a high aerosol (oil and/or particulate) loading require specialized sample collection devices and/or techniques. Significant concentrations of aerosolized oils quickly foul conventional particulate collection devices such as filters or cyclones. An ESP, designed and fabricated by Radian under a previous contract with ORNL, was used to remove the aerosolized oils from the process gas stream (2). This device permits the collection of samples that are essentially free of aerosolized oils from gas streams having an oil loading of above 1 g/Nm^3.

Particulate matter in gas streams which do not contain aerosolized oils may be collected on glass fiber filters. If stream temperatures are below 480°C (900°F), the glass fiber filter may be placed directly in the stream. If stream temperatures are above 480°C, filtration must occur outside of the stream because of the temperature limitations on the glass

TABLE 4. TYPICAL PHYSICAL CHARACTERISTICS OF PROCESS GAS STREAMS

Stream	Temperature °C	Temperature (°F)	Pressure kPa	Pressure (H_2O in.)	Velocity m/sec	Velocity (ft/sec)	Aerosolized Oils Loading g/Nm^3	Particulate Loading g/Nm^3
Combined Product Gas	218	(425)	6.0	(+24)	7.0	(23)	2.0E4	1.9E5
Raw Top Product Gas	93	(199)	6.0	(+24)	10.0	(33)	7.3E6	1.2E5
Cleaned Top Product Gas	88	(190)	6.0	(+24)	8.2	(27)	1.5E5	3.1E4
Raw Bottom Product Gas	514	(957)	7.2	(+29)	3.0	(10)	ND	5.7E5
Cleaned Bottom Product Gas	418	(784)	7.2	(+29)	2.7	(8.9)	ND	6.7E5

aEb = a x 10^b.
ND - Not detected.

fiber filter. Out-of-stream filters are usually held at just below 480°C in a temperature-controlled oven to minimize condensation of organic vapors that might contaminate and/or clog the filter.

Three basic hardware systems were used to collect samples from the five process streams. The systems and the streams on which they were used during the sampling and analysis effort are listed in Tables 5 and 6, and illustrated in Appendix C. Table 5 presents the hardware systems used to collect aerosol material, both oils and particulates, from the sample gases. Vapor collection systems followed the aerosol removal systems to provide samples for quantitation of vaporous parameters. Table 6 presents the collection systems for vaporous parameters.

Grab samples for quantitation of major gases, hydrocarbons, and sulfur species were collected in cleaned, silanized glass bombs. The sample gas was first filtered using a Teflon® filter. Moisture was then removed from the sample gas using a Perma-Pure Drier® which uses an osmotic membrane that is permeable to water vapor. The glass bomb was purged a minimum of three sample volumes and then pressurized with sample gas using a diaphragm pump with Teflon®-coated internals contacting the sample gas. If condensation appeared within the sample bomb, the sample was discarded and another sample was collected.

3.3 Combustion - Gaseous Emissions Sampling

Two combustion emissions streams were sampled during the test program. Product gas was combusted in Boilers No. 1 and No. 2, and ESP oil and natural gas were combusted in Boiler No. 3. These streams were characterized to develop an emissions data base and to evaluate potential environmental and health effects of the emissions from the combustion of gasification products. Following are descriptions of the sampling locations and techniques used to collect samples from the streams.

TABLE 5. SAMPLING SYSTEMS FOR PRODUCT GAS STREAMS

Sampling System	Combined Product Gas	Raw Top Product Gas	Cleaned Top Product Gas	Raw Bottom Product Gas	Cleaned Bottom Product Gas
Heat-Traced Probe					
• packing gland system • Type-S pitot • Type K thermocouple	X	X	X	X	X
In-Stack Filtration					
• glass fiber thimble	X		X		
Electrostatic Precipitator (ESP) followed by glass fiber thimble		X			
Out-of-Stack Filtration					
• glass fiber thimble in heated oven				X	X

TABLE 6. COLLECTION SYSTEMS FOR VAPOROUS PARAMETERS

Parameter	Collection System
Condensable Organics	Water-cooled condenser
Gas Phase Organics	XAD-2 resin
Trace Elements*	2-Smith-Greenburg impingers containing 500 mL of 0.2 M $(NH_4)_2S_2O_8$ + 0.2 M $AgNO_3$
NH_3	2-Smith-Greenburg impingers containing 200 mL of 5% H_2SO_4
HCN	2-Smith-Greenburg impingers containing 200 mL of 10% NaOH

*Gas phase mercury was collected using a gold amalgamation technique.

3.3.1 Sampling Locations

Combustion Emissions from Product Gas Boilers

The combustion emissions from Boilers No. 1 and No. 2 are combined in a rectangular duct which then is exhausted through a circular stack 30 m in height. The sampling location is about 7 m downstream of the point where these two streams converge. Five 3-inch ports are mounted equidistant along one side of the duct. Seven-point velocity traverses with a type-S pitot consistent with EPA Methods (3) were performed through each port; however, all other sampling was performed at a single point having the average flue gas velocity.

Combustion Emissions from Boiler No. 3

The combustion emissions from Boiler No. 3 are exhausted through a 1.4 m diameter metal duct which extends about 3 m above the roof of the building. Six-point velocity traverses were performed through two 4-inch pipe ports, mounted 90° with respect to each other, located about 1 m above the roof of the building. Velocity traverses and collection of samples were performed consistent with EPA Methods (3).

3.3.2 Sampling Techniques

The sampling methodology used to collect samples of the combustion emissions was considerably different from the methodology used to collect samples from the process streams. In gasification process streams, the presence of oils and pressurized gases having toxic and flammable components dictates the sampling protocol. In combustion emissions, trace organic and inorganic components are diluted with combustion air and require a methodology which concentrates these trace components.

Trace organic and trace element samples were collected from the combustion emission streams using the High Volume Source Assessment Sampling System (SASS) (1). The SASS draws sample gas at a rate of 0.1 Nm^3/min.,

or 4 SCF/min. (about eight times greater than conventional sampling systems), allowing the collection of a larger mass of sample material in a shorter period of time. The sample nozzle size was selected to give an isokinetic sampling rate initially; however, the rate was not varied to respond to variations in stream flow. The sample gas is drawn through a heat-traced probe, and particulate is removed by a heated cyclone followed by a glass fiber filter. A water-cooled condenser followed by XAD-2 resin collects condensable and gaseous organics. Downstream of the condenser and resin an impinger train containing 0.2 M $(NH_4)_2 S_2O_8$ + 0.2 M $AgNO_3$ is used for collection of trace elements.

Sulfur oxides and particulate matter were quantitated in the combustion emissions using combined EPA Methods 5 and 6. The sample gas was drawn isokinetically through a heated probe and the particulate was collected on a heated glass fiber filter. Sulfur oxides were collected in 3% hydrogen peroxide impingers downstream of the filter. Nitrogen oxides were quantitated in the combustion emissions using EPA Method 7. Grab samples for analysis of major gases, hydrocarbons, and sulfur species were collected through ports at each location that was not occupied by other sampling hardware.

3.4 Solids Sampling

Three solids streams were sampled during the test period. The three streams are:

- coal,
- gasifier ash, and
- cyclone dust.

Coal is stored in a series of hoppers inside the heating plant and is conveyed from the hoppers to sizing screens located above the coal feed lockhopper. From the screens, the coal is conveyed to a weigh hopper. Coal samples were collected as the coal fell from the conveyor belt into the weigh hopper. The samples were stored in 1-L polyethylene bottles.

Two hydraulically operated buckets remove gasifier ash from the ash pan and dump the ash onto belt conveyors which transport it to a storage area. The ash dewaters through screens which constitute the bottoms of the buckets. Gasifier ash samples were collected as the ash fell from the buckets onto the conveyor belt. Samples of gasifier ash were stored in 500-mL glass bottles having Teflon®-lined caps.

Dust removed from the bottom product gas by the cyclone is collected in a lockhopper. The dust is emptied periodically from the lockhopper and augered to drums and stored for disposal. Samples of the cyclone dust were collected from the auger and were stored in 500-mL glass jars with Teflon®-lined caps.

3.5 Liquids Sampling

The three liquid streams listed below were sampled during the testing period:

- ESP oil to storage,
- ESP oil to Boiler No. 3, and
- ash pan water.

Oil removed from the top product gas by the electrostatic precipitator (ESP) flows by gravity in heat-traced, insulated lines from the ESP to a heated, insulated intermediate storage tank. Samples of the ESP oil (500 mL) were collected through a valve in the transport line between the ESP and storage tank and were stored in glass bottles having Teflon®-lined caps.

During combustion of ESP oil in Boiler No. 3, ESP oil from an underground heated storage tank was pumped to the boiler. Samples of the ESP oil to Boiler No. 3 were collected through a valve mounted in the transfer line between the pump and boiler. Samples of the ESP oil to Boiler No. 3 (500 mL) were stored in glass bottles having Teflon®-lined caps.

Ash pan water samples were collected directly from the ash pan. Samples for analysis of extractable organics were collected and stored in 1-L glass bottles with Teflon®-lined caps; samples for trace elements analysis were collected and stored in 1-L polyethylene bottles. Samples for analysis of these water quality parameters performed on site were collected in 1-L glass bottles.

SECTION 4
ANALYTICAL METHODOLOGIES

Analytical methodologies are detailed in Appendix D and in the IERL-RTP Procedures Manual: Level I Environmental Assessment (1). The following section briefly describes the individual techniques and provides an overview of the analytical program. Figure 3 gives the analytical matrix for the types of samples collected and the analyses performed. Results of the analyses are presented in Appendix B.

4.1 Organic Screening Analyses

The organic screening analyses were performed according to the procedures described in Section 6 of Appendix D. The use of diethyl ether as an extraction solvent following the methylene chloride extraction was an addition to the cited methods. This step was performed to increase the extraction efficiency for highly polar organic compounds.

Organic screening analyses included the determination of total chromatographable organics (TCO) using a gas chromatographic technique and the gravimetric portion (GRAV) by a gravimetric method. The TCO determination quantitates organics with a boiling point range of 100°C to 300°C; the GRAV determination quantitates organic compounds having boiling points greater than 300°C. Previous work (4) indicates that the overlap of compounds determined by the TCO and GRAV analyses may not be significant.

Those samples with a combined TCO and GRAV value of greater than 15 mg were subjected to liquid chromatographic (LC) fractionation. These samples included gasifier ash, ESP oil to Boiler No. 3, and combined gas (condensable and gas phase organics). The LC fractionation was performed according

	Gas Analyses														Liquids Analyses			Solids Analyses			
	Major Components*	Hydrocarbons†	Sulfur Species#	BTX Organics**	Aerosol Organics	Condensable Organics	Gas Phase Organics	NH_3	HCN	NO_x	SO_2	Trace Elements††	Oil Loading	Particulate Loading	Water Quality Parameters##	Extractable Organics	Trace Elements††	Proximate/Ultimate	Extractable Organics	Trace Elements††	RCRA Extraction Procedure
Combined Product Gas	X	X	X	X	X	X	X	X	X			X	X	X							
Combustion Emissions from Product Gas Boilers	X	X	X	X	X	X	X	X	X	X	X	X		X							
Cleaned Top Product Gas	X	X	X	X	X			X	X				X	X							
Raw Top Product Gas	X	X	X	X	X			X	X				X	X							
Cleaned Bottom Product Gas	X	X	X	X				X	X					X							
Raw Bottom Product Gas	X	X	X	X				X	X					X							
Combustion Emissions from Boiler No. 1 Firing ESP Oil	X	X	X	X	X	X	X	X	X	X	X	X		X							
Combustion Emissions from Boiler No. 1 Firing Natural Gas	X	X	X							X	X										
ESP Oils to Boiler No. 1																		X	X	X	
Coal																		X		X	
Gasifier Ash																		X	X	X	X
Cyclone Dust																		X	X	X	X
ESP Oils																		X			
Ash Pan Water															X	X	X				

*Major components - CO, CO_2, H_2, O_2, N_2, CH_4
†Hydrocarbons - CH_4, C_2H_4, C_2H_6, C_3, C_4, C_5, C_6
#Sulfur species - H_2S, COS, CS_2, SO_2, methyl mercaptan, ethyl mercaptan, thiophene
**BTX - benzene, toluene, xylene
††Trace elements - SSMS, ICPES, AAS
Water quality parameters - PO_4 , Cl^-, F^-, $S^=$, $SO_3^=$, CN^-, SCN^-, $SO_4^=$, NH_3, COD, BOD, TOC, TSS, TDS, pH, conductivity, phenol

Figure 3. An analytical matrix for samples collected at Foster Wheeler/ Stoic two-stage gasifier (UMD).

to the procedure given in Section 6.8 of Appendix D. TCO and GRAV analyses were performed on each of the seven fractions of the samples and on an analytical blank.

4.2 Gas Chromatographic Analyses

4.2.1 Process Gases Analyses

Samples of the combined gas, treated and raw top product gas, treated and raw bottom product gas, and the combustion emissions from the product gas boilers and Boiler No. 3 were characterized on site for major components, hydrocarbons, and sulfur species by gas chromatography. In addition, samples were collected for off-site analysis for benzene, toluene, and xylene (BTX). Analyses were performed according to the procedures in Sections 5 and 6.4 of Appendix D.

4.2.2 Gas Chromatography - Hall Detector

Composited sample extracts were prepared from the gasifier ash, cyclone dust, ash pan water, and ESP oil to Boiler No. 3. These, and sample extracts of organic vapors and condensable organics in the combined product gas as well as combustion emissions from the product gas boilers and Boiler No. 3 firing ESP oil, were screened by gas chromatography. The analyses were performed using a gas chromatograph equipped with a Hall 700A electrolytic conductivity detector (HECD). The HECD may be operated in the nitrogen-, halogen-, or sulfur-specific mode. Using the HECD in each of the three modes provides data analogous to TCO data for nitrogen-, halogen-, and sulfur-containing organic compounds. A screening analysis for these compound classes was conducted because many organic compounds of health or ecological significance contain these heteroatoms.

4.2.3 Gas Chromatography - Electron Capture Detector

The sample extracts listed in 4.2.2 were screened for polychlorinated biphenyls (PCBs) using a gas chromatograph equipped with an electron capture

detector (ECD). This method provides quantitation and identification of various PCBs present in the extract.

4.2.4 Gas Chromatography - Mass Spectrometry

Gas chromatography - mass spectrometric (GC-MS) analyses of the composited extracts listed in 4.2.2 were performed to provide identification and quantitation of specific organic compounds. The analyses used a computer-assisted GC-MS system for the extractable EPA Priority Pollutants. Priority pollutant analyses were performed to satisfy the data needs of EPA's Effluent Guideline Division. It additionally provided a rapid and cost-effective means of identifying and quantitating other compounds such as polynuclear aromatics (PNAs).

In addition to priority pollutant compounds, the major non-priority pollutant peaks in each sample were quantitated relative to d_{10}-anthracene. This method provided a more complete characterization of organic compounds in the sample.

Finally, the total unidentified chromatographable mass in each extract was quantitated relative to d_{10}-anthracene.

4.3 Aerosol Organics and Particulate Loading

Aerosol organics and particulate loadings were determined by gravimetric analysis of filter catches. Particulate is defined as the material remaining following extraction with methylene chloride and diethyl ether. The aerosol loading is the sum of the aerosol (extractable) organic loading and the particulate loading.

4.4 Trace Elements Analysis

Analyses were performed for 17 elements by inductively coupled argon plasma emission spectrometry (ICPES) and 4 elements by atomic absorption spectrophotometry (AAS). In addition, the samples, except leachates, were

subcontracted to Commercial Testing and Engineering Co., Chicago, Illinois, for spark source mass spectral (SSMS) analysis for 75 elements. A list of the elements and methods used for analyses are given in Table 7. The following samples were analyzed:

- coal,
- gasifier ash,
- cyclone dust,
- ESP tar to Boiler No. 3,
- ash pan water,
- trace metals impinger catches,
- XAD-2 resin extracts (SSMS only),
- RCRA leachate of gasifier ash, and
- RCRA leachate of cyclone dust.

4.5 Water Quality and Ionic Species Analysis

Selected water quality parameters in ash pan water samples and ammonia and cyanide in the impinger catches were analyzed on site. More stable parameters were analyzed in preserved samples at Radian's Austin laboratory. Table 8 lists the water quality parameters analyzed and preservation techniques. Preservation procedures used were recommended by EPA in Methods for Chemical Analysis for Waters and Wastes (5).

4.6 Oxides of Nitrogen and Sulfur

Combustion emissions from the product gas boilers and Boiler No. 3 firing both ESP oil and natural gas were analyzed for oxides of nitrogen (NO_x) and sulfur (SO_x). Nitrogen oxide samples were collected in a dilute sulfuric acid-hydrogen peroxide solution and analyzed spectrophotometrically. Sulfur oxide samples were collected in hydrogen peroxide solutions and were analyzed titrimetrically.

TABLE 7. ANALYTICAL METHODS USED FOR TRACE ELEMENT ANALYSIS

	SSMS	ICPES	AAS		SSMS	ICPES	AAS
Aluminum	X	X		Neodymium	X		
Antimony	X		X	Nickel	X	X	
Arsenic	X		X	Niobium	X		
Barium	X	X		Osmium	X		
Beryllium	X			Palladium	X		
Bismuth	X			Phosphorus	X		
Boron	X	X		Platinum	X		
Bromine	X			Potassium	X	X	
Cadmium	X			Praseodymium	X		
Calcium	X	X		Rhenium	X		
Cerium	X			Rhodium	X		
Cesium	X			Rubidium	X		
Chlorine	X			Ruthenium	X		
Chromium	X	X		Samarium	X		
Cobalt	X	X		Scandium	X		
Copper	X	X		Selenium	X		X
Dysprosium	X			Silicon	X		
Erbium	X			Silver	X		
Europium	X			Sodium	X	X	
Fluorine	X			Strontium	X		
Gadolinium	X			Sulfur	X		
Gallium	X			Tantalum	X		
Germanium	X			Tellurium	X		
Gold	X			Terbium	X		
Hafnium	X			Thallium	X		
Holmium	X			Thorium	X		
Iodine	X			Thulium	X		
Iridium	X			Tin	X		
Iron	X	X		Titanium	X	X	
Lanthanum	X			Tungsten	X		
Lead	X			Uranium	X		
Lithium	X			Vanadium	X	X	
Lutetium	X			Ytterbium	X		
Magnesium	X	X		Yttrium	X		
Manganese	X	X		Zinc	X	X	
Mercury	X		X	Zirconium	X		
Molybdenum	X	X					

TABLE 8. WATER QUALITY PARAMETERS & PRESERVATION TECHNIQUES

Parameter	Location	Method	Preservation
pH	OS*	Corning Model 125 pH meter	None
Conductivity	OS	YSI Model 33 conductivity meter	None
Phosphate	Lab†	Colorimeteric	H_2SO_4, pH <2, cool
Chloride	Lab	Colorimetric	Cool
Fluoride	Lab	Specific Ion Electrode	Cool
Sulfate	Lab	Turbidimetric	Cool
Sulfide	OS	Titrimetric	Zinc acetate, pH >12
Sulfite	OS	Titrimetric	Zinc acetate, pH >12
Nitrate	Lab	Colorimetric	Cool
Cyanide	OS	Distillation/colorimetric	$S^{=}$ removed, pH >12, cool
Thiocyanate	OS	Extraction, colorimetric	$S^{=}$ removed, pH >12, cool
Ammonia	OS	Distillation, titrimetric	H_2SO_4, cool
COD	OS	Reflux, titrimetric	pH <2, cool
BOD	Lab	Digestion, titrimetric	Cool
TOC	Lab	Beckman 915B TOC analyzer	pH <2, cool
TSS	Lab	Gravimetric	Cool
TDS	Lab	Gravimetric	Cool
Phenol	Lab	Distillation, colorimetric	H_2PO_4, pH <4, cool
Trace Metals	Lab	SSMS, ICPES, AAS	HNO_3, pH <2

*on site
†Radian's Austin laboratory

4.7 Leaching Studies

Composited samples of gasifier ash and cyclone dust were leached using Resource Conservation and Recovery Act Extraction Procedure (RCRA-EP) protocol (6). Elemental analyses were performed as described in Section 4.4.

4.8 Proximate/Ultimate Analysis

Samples of coal, gasifier ash, cyclone dust, and ESP oil were subcontracted to Commercial Testing and Engineering Co., Chicago, Illinois, for proximate/ultimate determinations in accordance with ASTM methods (7).

4.9 Analytical Quality Assurance

Certified gas standards and standard solutions were analyzed on site during the sampling effort to provide calibration data and quality assurance.

Samples that were not analyzed on site were preserved and returned for laboratory analysis within preservation time limits. All samples were logged on site, and logged entries were cross-verified upon receipt in the laboratory. The on-site log is presented in Appendix A.

Solvent blanks, impinger solution blanks, charcoal tube blanks, and blank XAD-2 resins for trace elements were analyzed in the laboratory and included in the subcontracted analyses. Data for blank XAD-2 resins are presented in Appendices A and B. Blanks were obtained from LC column fractionation for all eluents used. The same solvent lots were used throughout the organic analysis, and blanks were analyzed for TCO and GRAV.

SECTION 5
RESULTS

Summarized results of the evaluation of major process and discharge streams are discussed in this section. The discharge and process streams addressed are as follows:

- discharge streams
  --emissions from the product gas boilers
  --emissions from the ESP oil boiler (Boiler No. 3)
  --gasifier ash
  --cyclone dust
  --ash pan water
- process streams
  --combined product gas
  --ESP oil to Boiler No. 3

Detailed analytical results are presented in Appendix B. The results are discussed in this section in the following order:

- Process Flow Rates and Material and Component Balance
- Elemental Mass Flow Rates
- Elemental Behavior
- Extractable Organics
- Gas Composition
- Efficiency of Gas Cleanup Devices
- Water Quality
- RCRA Leaching

5.1 Process Flow Rates and Material and Component Balances

Material and component balances have been established for gasification and combustion processes at the UMD facility. The combustion processes include combustion of product gas and combustion of ESP oil. Figure 4 is a schematic of the UMD facility; the three process areas for which balances have been determined are outlined. The balance around Boiler No. 3 is independent of balances around other process areas. The balances around the gasifier and the product gas boilers support each other because the combined product gas is a major outlet stream of the gasifier (~90 percent of the mass of the outlet streams of the gasifier) and is the fuel component to the product gas boilers (~17 percent of the mass of inlet streams to the boilers).

5.1.1 Gasification Process

Material and Component Balances

Figure 5 is a schematic of the gasification process and indicates the inlet and outlet streams that were considered in establishing the material and component balances around the gasifier. The material and component balances during the period 12:01 a.m. February 23, 1981 to 12:00 midnight February 27, 1981 are presented in Table 9. Closure of the balance is evaluated by the ratio of total mass flow of a component leaving the process to total mass flow of a component entering the process, with closure defined as a ratio of 1.0. The limits of the ratio are a measure of the degree of uncertainty associated with the ratio. The material and component balances close within 3 to 14 percent, with sulfur and carbon displaying the greatest difference between mass out and mass in. Less sulfur and carbon was accounted for in the outlet streams than in the inlet streams.

Flow rates for a number of the streams were determined from plant operation log data or were measured by UMD plant personnel. For example, the flow rate for dry coal was determined by multiplying the number of coal

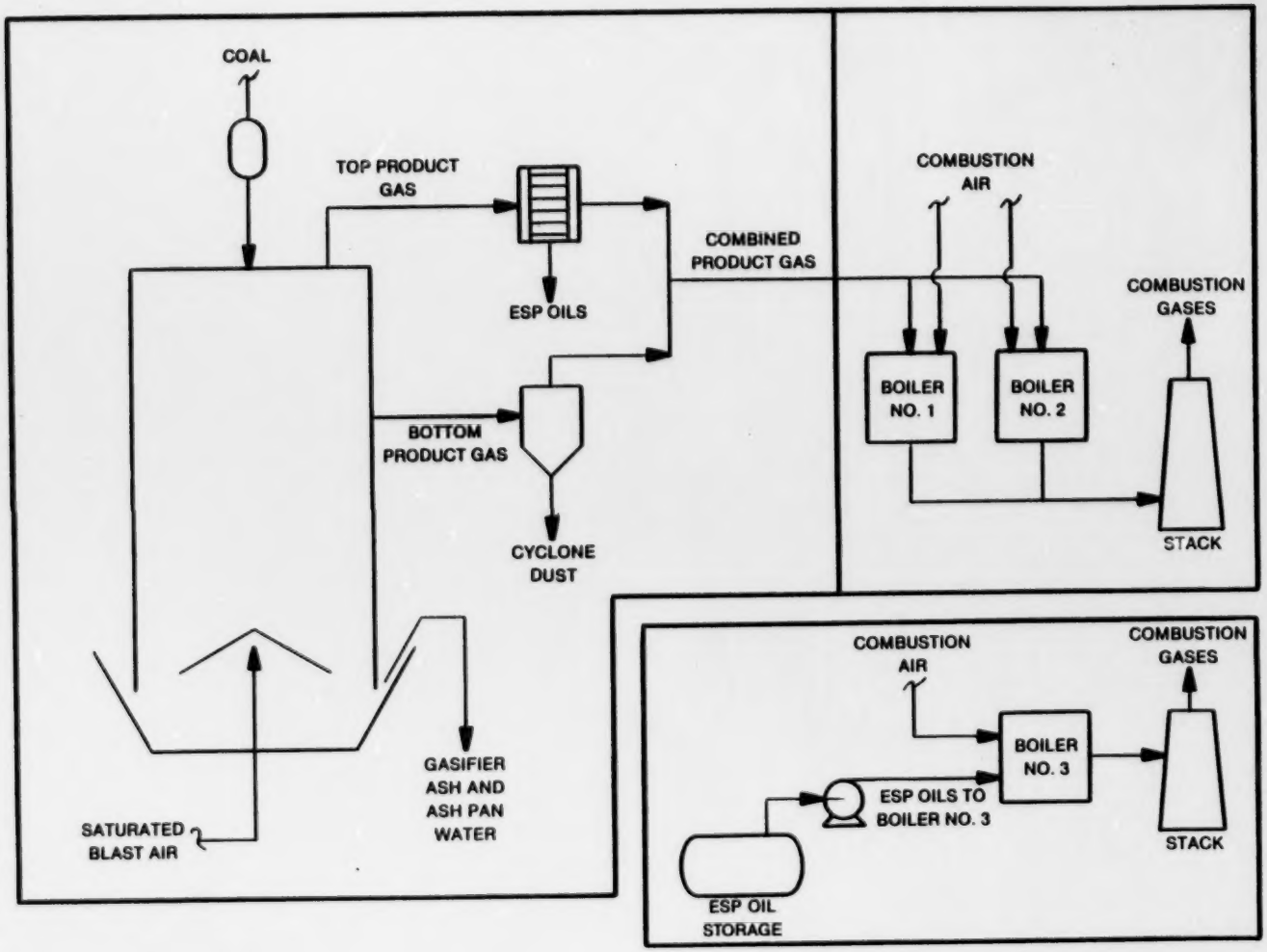


Figure 4. Schematic of UMD gasification and heating facility indicating balance boundaries.

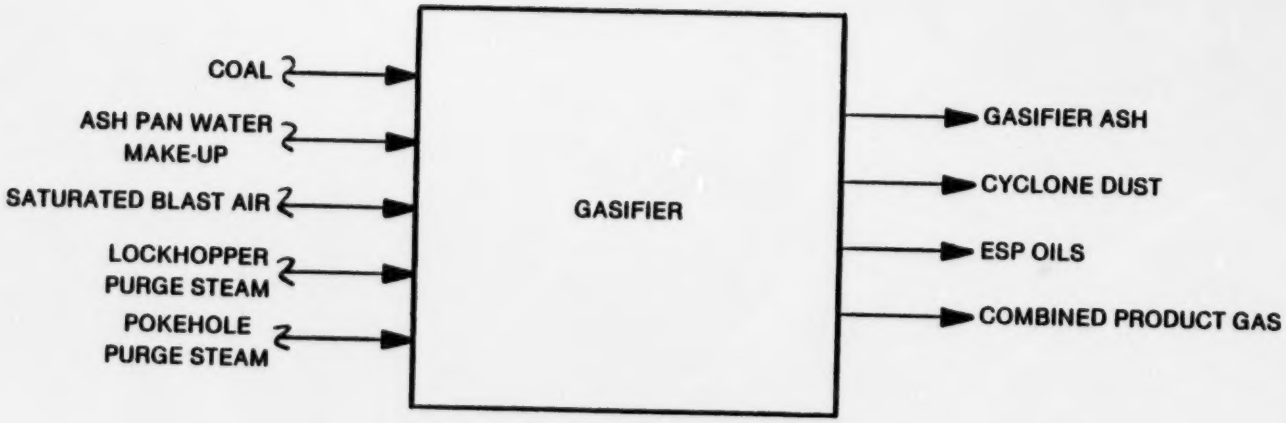


Figure 5. Schematic of mass balance streams for the Foster Wheeler/Stoic two-stage gasifier at UMD.

TABLE 9. MATERIAL AND COMPONENT BALANCES OF THE FOSTER WHEELER/STOIC TWO-STAGE GASIFIER - UMD

	Total (g/s)	Ash (g/s)	Carbon (g/s)	Hydrogen (g/s)	Oxygen + Argon (g/s)	Nitrogen (g/s)	Sulfur (g/s)
	Rate ±σ	Rate ±σ	Rate ±σ	Rate ±σ	Rate ±σ	Rate ±σ	Rate ±σ
Inlet Streams							
Coal (dry)	270±27†	26±6	190±19	12±1.2	38±4	3.9±0.4	1.4±0.2
Moisture in Coal	30±3#			3±0.3	27±3		
Ash Pan Water-Makeup	7±4†			1±0.5	6±3		
Blast Air	620±120†				145±28	475±95	
Blast Air Steam	70±7†			8±0.8	62±6		
Lockhopper Purge Stream	16±4††			2±0.5	14±4		
Pokehole Purge Steam	6±2††			1±0.3	5±1		
ΣIn	1019±123	26±6	190±19	27±1.7	297±30	478±95	1.4±0.2
Discharge Streams							
Gasifier Ash (dry)	35±4††	27±4	7.2±2.3	0.06±0.02	0.37±0.51	0.07±0.03	0.1±0.02
Water in Gasifier Ash	9±0.9#			1±0.1	8±0.8		
Cyclone Dust	0.2±0.1††	0.05±0.03	0.14±0.07				
ESP Oil	4±1		3.4±0.9	0.4±0.10	0.1±0.03	0.02±0.01	
Combined Product Gas (dry)	930±190#		160±34	17±4	230±48	523±109	1.1±0.2
Water in Combined Product Gas	75±15#			8±1.6	67±13		
ΣOut	1053±191	27±4	170±34	26±4	305±50	523±109	1.2±0.2
ΣOut/ΣIn	1.03	1.04	0.89	0.96	1.03	1.09	0.86

†Flow rate determined from plant process data.
††Flow rate measured by UMD plant personnel.
#Flow rate measured by Radian.
*Error limit based on judgement value.

Note: All flow rates and error limits not footnoted have been determined empirically.
All error limits are one standard deviation (σ).

lockhopper dumps by the scale calibration factor (weight/dump) and correcting the resultant value for the moisture content of the coal (which was determined by proximate/ultimate analysis). Other flow rates were determined from measurements made by Radian personnel. For example, the flow rate of the combined product gas was calculated from velocity measurements and molecular weight determinations made by Radian personnel.

Confidence limits in any stream indicated in the material balance table are the result of calculations which take into consideration analytical and stream flow rate variability. The confidence limits were calculated from

$$\sigma c = \sqrt{[\sigma m_{(c)}]^2 + [\sigma f_{(c)}]^2}$$

where:

Confidence limit = c = standard deviation for flow rate of a component "c"

$m_{(c)}$ = analytical standard deviation for component "c"

$f_{(c)}$ = flow rate standard deviation for stream containing component "c"

The confidence limits for the total process mass flow rate of each component were calculated by taking the square root of the sum of the squares of the standard deviations of the component mass flow in each stream.

Gasifier Efficiency

Based on the data taken during the test period, the UMD gasifier had cold gas efficiency of approximately 80 percent. Cold gas efficiency is a measure of a gasifier's ability to convert potential combustion energy in coal to potential combustion energy of the dry, tar-free product gas (higher heating value basis). The calculated cold gas efficiency value (≈80%) should not be taken as representative of this gasifier's typical performance. This value is not supported by a detailed energy balance since heat balance and efficiency calculations were not within the scope of this environmental characterization effort.

5.1.2 Combustion Processes

Material and component balances were established around the two combustion processes at the UMD heating plant. Boilers No. 1 and No. 2 fire the combined product gas and exhaust the flue gases through a common stack. Boiler No. 3 fires the ESP oil; test data were also gathered during firing of natural gas in Boiler No. 3. Figures 6 and 7 present schematics of the inlet and outlet streams of the two combustion processes.

Product Gas Boilers

Boilers No. 1 and No. 2 fire the combined product gas and are termed the "product gas boilers". Material and component balances have been determined for the product gas boilers and are presented in Table 10. The flow rate of the combustion air was determined by closing the nitrogen balance, i.e., the total nitrogen in the inlet streams was set equal to the total nitrogen in the outlet streams by adjusting the combustion air flow rate. All other flow rates were determined experimentally. Because of equipment limitations, sampling on inlet and outlet streams could not be performed concurrently.

Hydrogen exhibits the poorest balance with a closure of 1.5. Sulfur also exhibits poor closure, with one-third more sulfur found in the emissions from the boilers than was found in the combined product gas. Data for oxides of nitrogen are also presented and correlate reasonably well with the concentration of ammonia and hydrogen cyanide in the product gas streams (see Section 5.5). Based on the limitations that necessarily must be placed on the data as a result of sampling inlet and outlet streams at different times, the calculated balances appear to be reasonable.

Boiler No. 3

Material and component balances were determined around Boiler No. 3 during combustion of ESP oils and during combustion of natural gas. Emissions from the combustion of natural gas were measured to provide a basis

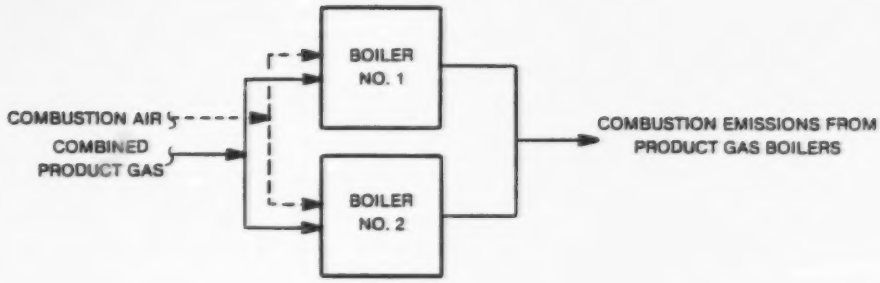


Figure 6. Schematic of mass balance streams for product gas boilers at UMD facility.

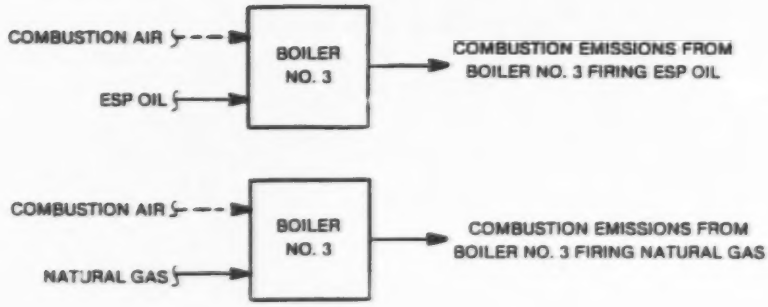


Figure 7. Schematic of mass balance streams for Boiler No. 3 at UMD facility.

TABLE 10. MATERIAL AND COMPONENT BALANCES OF THE PRODUCT GAS BOILERS - UMD

	Total (g/s) Rate ± σ	Carbon (g/s) Rate ± σ	Hydrogen (g/s) Rate ± σ	Oxygen + Argon (g/s) Rate ± σ	Nitrogen (g/s) Rate ± σ	Sulfur (g/s) Rate ± σ	NH_3, HCN (g/s) Rate ± σ	NO_x (as NO_2) (g/s) Rate ± σ
Inlet Streams								
Combined Product Gas (dry)	930±190#	160±34	17±4	230±48	523±109	1.1±0.2	0.80±0.16	NA
Water in Combined Product Gas	75±15#		8±1.6	67±13				
Combustion Air	4800±1200†		4±1	1152±280	3680±920			
Σ In	5805±1215	160±34	29±4	1449±284	4200±926	1.1±0.2	0.80±0.16	NA
Discharge Streams								
Product Gas Boilers Combustion Emissions	5592±560#	190±21	0.1	1200±132	4200±460	1.5±0.2	NA**	0.72±0.08
Water in Combustion Emissions	340±34		38±4	300±33				
Σ Out	5932±560	190±21	38±4	1500±136	4200±460	1.5±0.2	NA	0.72±0.08
Σ Out/Σ In	1.02±0.23	1.19	1.31	1.03	1.00	1.36		

†Combustion air flow rate was determined by closing nitrogen balance.
#Flow rate measured by Radian.
ΔError limit based on judgement value.
**NA - not applicable.
Note: All flow rates and error limits not footnoted have been determined empirically.
All error limits are one standard deviation (σ).

for comparison with the emissions during combustion of ESP oils. The material and component balances are presented in Table 11. The flow rate of ESP oil was determined from plant process data. The flow rate of the combustion air was determined by closing the nitrogen balance, i.e., by adjusting the value for combustion air flow rate to make the total nitrogen in the inlet streams equal to the total nitrogen in the outlet streams. All other flow rates were determined by Radian personnel. All components except sulfur exhibit closure; over one and one-half times more sulfur was measured in the flue gas than in the ESP oil fed to Boiler No. 3. Sulfur also exhibits the greater uncertainty associated with the determination of closure.

5.2 Elemental Mass Flow Rates

The mass flow rates of trace elements in feed streams and discharge streams of the gasifier, product gas boilers, and the ESP oil boiler were determined from the elemental concentration and flow rate of each stream. Elemental concentrations are presented in Tables B-29 through B-36 (Appendix B). The elemental mass flow rates of gasification streams are presented in Table 12; the elemental mass flow rates of product gas boilers streams and streams of Boiler No. 3 during combustion of ESP oils are presented in Table 13.

5.3 Elemental Behavior

5.3.1 Predictive Value of Elemental Behavior Information

Elements enter the gasification process with the coal and other feed streams, including water, and leave in the various product, by-product, and discharge streams. The distribution of elements in the discharge streams can provide a basis for predicting how and where elements of concern might enter the environment. Such predictions may be useful to designers of gas clean-up and pollution control systems.

Several discharge streams from the two-stage gasification process are vehicles for elemental emissions. The gasifier ash carries the greatest

TABLE 11. MATERIAL AND COMPONENT BALANCES OF BOILER NO. 3 FIRING ESP OIL - UMD

	Total (g/s)	Carbon (g/s)	Hydrogen (g/s)	Oxygen + Argon (g/s)	Nitrogen (g/s)	Sulfur (g/s)	NO_x (as NO_2) (g/s)
	Rate ± σ	Rate ± σ	Rate ± σ	Rate ± σ	Rate ± σ	Rate ± σ	Rate ± σ
Inlet Streams							
ESP Oil to Boiler No. 3	250±25†	210±21	27±3	8±1	1.2±0.7	0.60±0.16	
Combustion Air	5100±1275††	0.7±0.2		1200±300	3900±975		
ΣIn	5350±1275	211±21	27±3	1200±300	3900±975	0.60±0.16	
Discharge Streams							
Boiler No. 3 Firing ESP Oil	5200±520#	230±25		1100±121	3900±429	0.95±0.10	0.1
Water in Combustion Emissions	230±23#		26±3	200±20			
ΣOut	5430±521	230±25	26±3	1300±123	3900±429	0.95±0.10	0.1
ΣOut/ΣIn	1.01	1.09	0.96	1.08	1.00	1.58	

††Combustion air flow rate was determined by closing nitrogen balance.
†Flow rate determined from plant process data.
#Flow rate measured by Radian.
*Error limit based on judgement value.

Note: All flow rates and error limits not footnoted have been determined empirically.
All error limits are one standard deviation (σ).

TABLE 12. FOSTER WHEELER/STOIC TWO STAGE GASIFIER - UMD
ELEMENTAL MASS FLOW RATES - GASIFICATION PROCESS

Element	Coal (μg/s)	Gasifier Ash (μg/s)	Cyclone Dust (μg/s)	ESP Oils (μg/s)	Ash Pan Water (μg/s)	Combined Product Gas††† (μg/s)
Aluminum*	3.5E6	2.7E6	5.2E3	220	3.2	5.0E3
Antimony**	<54	<7.0	3.8	0.8	<0.02	11
Arsenic**	490	850	6.2	3.3	<0.02	15
Barium*	1.3E5	1.2E5	64	21	14	60
Beryllium	81	31	0.16	ND	ND	0.15
Bismuth	ND	<3.5	0.80	0.12	ND	0.75
Boron*	6.8E3	2.4E4	20	4.0	40	170
Bromine	540	100	1.4	0.40	0.9	40
Cadmium	270	180	0.60	ND	ND	0.55
Calcium*	9.0E5	1.7E6	2.4E3	120	5.5E3	2.2E3
Cerium	3.0E3	3.5E3	5.6	0.24	ND	5.2
Cesium	81	280	0.14	ND	<0.01	0.13
Chlorine	7.3E3	350	17	1.2	6.3	400
Chromium*	1.4E3	1.5E3	4.0	<0.4	0.41	78
Cobalt*	430	420	0.86	<2.4	0.16	0.80
Copper*	1.3E3	1.1E3	4.4	0.64	0.53	280
Dysprosium	ND	210	0.80	ND	ND	0.74
Erbium	ND	100	0.16	ND	ND	0.15
Europium	ND	35	0.20	ND	ND	0.18
Fluorine	1.9E3	3.9E3	>200	16	0.45	180
Gadolinium	ND	140	0.40	ND	ND	0.37
Gallium	1.4E3	800	56	0.28	0.18	52
Germanium	54	25	3.8	≤0.08	ND	3.5
Gold	ND	ND	ND	ND	ND	ND
Hafnium	ND	70	0.40	ND	ND	≤0.37
Holmium	ND	140	0.20	ND	ND	0.18
Iodine	110	10	0.80	0.24	0.06	0.74
Iridium	ND	ND	ND	ND	ND	ND
Iron*	9.7E5	1.4E6	2.4E3	680	<0.07	2.6E3
Lanthanum	2.4E3	6.3E3	4.0	0.20	ND	3.7
Lead	810	420	170	1.6	0.09	160
Lithium	3.2E3	2.2E3	5.4	0.12	1.8	43
Lutetium	ND	10	ND	ND	ND	ND
Magnesium*	2.0E5	4.2E5	480	<22	2.5	440
Manganese*	6.5E3	1.5E4	9.5	2.2	0.07	17
Mercury**	<19	10	0.15	0.64	0.38	2.2
Molybdenum*	780	560	1.5	2.6	1.1	6.0
Neodymium	240	660	0.40	ND	ND	0.37

(Continued)

TABLE 12. (Continued)

Element	Coal (μg/s)	Gasifier Ash (μg/s)	Cyclone Dust (μg/s)	ESP Oil (μg/s)	Ash Pan Water (μg/s)	Combined Product Gas††† (μg/s)
Nickel	1.2E3	1.1E3	3.2	<1.2	0.16	120
Niobium	1.1E3	1.3E3	2.0	ND	0.02	1.8
Osmium	ND	ND	ND	ND	ND	ND
Palladium	ND	ND	ND	ND	ND	ND
Phosphorus	>2.7E5	3.5E4	>200	12	0.9	260
Platinum	ND	ND	ND	ND	ND	ND
Potassium*	2.6E5	2.9E5	540	112	120	500
Praseodymium	540	560	1.0	<0.04	ND	0.9
Rhenium	ND	ND	ND	ND	ND	ND
Rhodium	ND	ND	ND	ND	ND	ND
Rubidium	1.1E3	2.1E3	1.8	0.08	0.27	2.0
Ruthenium	ND	ND	ND	ND	ND	ND
Samarium	540	210	0.80	ND	ND	0.74
Scandium	20	70	0.20	<0.04	<0.02	0.18
Selenium**	97	21	0.52	<1.2	<0.03	1.6
Silicon	>2.7E5	>3.5E4	>200	16	3.6	93
Silver	220	11	≤0.40	0.80	ND	0.37
Sodium*	4.9E4	5.3E4	140	200	40	1.1E3
Strontium	2.7E5	3.5E4	150	1.6	>90	140
Sulfur	1.4E6†	9.8E4†	2.0E3†	9.6E3†	840††	1.16***
Tantalum	ND	21	ND	ND	ND	ND
Tellurium	110	7.0	0.20	ND	0.04	0.18
Terbium	ND	35	0.16	ND	ND	0.15
Thallium	ND	14	2.4	ND	ND	2.2
Thorium	1.1E3	1.0E3	1.6	ND	≤0.09	1.5
Thulium	ND	7.0	ND	ND	ND	ND
Tin	110	18	15	0.15	ND	14
Titanium*	1.2E5	6.4E4	160	13	1.3	140
Tungsten	ND	70	0.80	ND	ND	0.74
Uranium	810	670	1.4	ND	≤0.09	1.3
Vanadium*	2.6E3	2.3E3	4.8	10	0.99	4.5
Ytterbium	ND	70	ND	ND	ND	ND
Yttrium	3.8E3	1.8E3	3.2	ND	0.45	3.0
Zinc*	1.4E3	530	120	2.9	0.08	160
Zirconium	8.4E3	7.0E3	11	0.32	0.09	14

*Analysis performed by ICPES.
**Analysis performed by AAS.
***Analysis performed by FPD/GC.
†Ultimate analytical result.
††Water quality analytical result.
†††Includes particulate, impinger, and oil analyses.
ND - not detected.
aEb = a x 10^b

TABLE 13. FOSTER WHEELER/STOIC TWO STAGE GASIFIER - UMD ELEMENTAL MASS FLOW RATES - COMBUSTION PROCESSES

Element	Combined Product Gas††† (μg/s)	Combustion Emissions from Product Gas Boilers††† (μg/s)	ESP Oil to Boiler No. 3 (μg/s)	Combustion Emissions from Boiler No. 3 Firing ESP Oil††† (μg/s)
Aluminum*	5.0E3	6.7E3	1.4E4	7.8E3
Antimony**	11	<4.2	50	<4.5
Arsenic**	15	<6.4	200	<7.0
Barium*	60	53	1300	<48
Beryllium	0.15	0.15	ND	0.16
Bismuth	0.75	0.73	75	0.80
Boron*	170	16	<250	380
Bromine	40	33	25	1.3
Cadmium	0.55	2.0	ND	0.61
Calcium*	2.2E3	2.0E3	7.5E3	2.6E3
Cerium	5.2	5.2	15	5.6
Cesium	0.13	0.13	ND	0.14
Chlorine	400	16	75	17
Chromium*	78	14	<25	1600
Cobalt*	0.80	0.71	150	27
Copper*	280	3.7	40	12
Dysprosium	0.74	0.74	ND	0.80
Erbium	0.15	0.15	ND	0.16
Europium	0.18	0.18	ND	0.20
Fluorine	180	170	1.0E3	190
Gadolinium	0.37	0.37	ND	0.40
Gallium	52	54	18	<57
Germanium	3.5	3.5	<5.0	3.8
Gold	ND	ND	ND	ND
Hafnium	≤0.37	≤0.37	ND	≤0.40
Holmium	0.18	0.18	ND	0.20
Iodine	0.74	0.98	15	0.80
Iridium	ND	ND	ND	ND
Iron*	2.6E3	2.3E3	4.3E4	1.0E4
Lanthanum	3.7	3.7	13	4.0
Lead	160	160	100	0.53
Lithium	43	<4.8	7.5	10
Lutetium	ND	ND	ND	ND
Magnesium	440	440	<1400	480
Manganese*	17	10	130	170
Mercury**	2.2	45	40	110
Molybdenum*	6.0	9.2	163	120

(Continued)

TABLE 13. (Continued)

Element	Combined Product Gas††† (μg/s)	Combustion Emissions from Product Gas Boilers††† (μg/s)	ESP Oil to Boiler No. 3 (μg/s)	Combustion Emissions from Boiler No. 3 Firing ESP Oil††† (μg/s)
Neodymium	0.37	ND	ND	0.40
Nickel*	<120	14	<75	1.1E3
Niobium	1.8	1.7	ND	2.0
Osmium	ND	ND	ND	ND
Palladium	ND	ND	ND	ND
Phosphorus	260	170	750	200
Platinum	ND	ND	ND	ND
Potassium*	500	85	7.0E3	1.4E3
Praseodymium	0.9	0.9	<2.5	1.0
Rhenium	ND	ND	ND	ND
Rhodium	ND	ND	ND	ND
Rubidium	2.0	1.5	5.0	1.8
Ruthenium	ND	ND	ND	ND
Samarium	0.75	0.75	ND	0.80
Scandium	0.18	≤0.80	<2.5	0.19
Selenium**	1.6	1.5	75	1.6
Silicon	93	180	1.0E3	>200
Silver	0.37	0.37	50	≤0.40
Sodium*	1.1E3	140	1.3E4	300
Strontium	140	130	100	150
Sulfur	1.1E6***	1.5E6††	6.0E5†	8.0E5††
Tantalum	ND	ND	ND	ND
Tellurium	0.18	0.18	ND	0.20
Terbium	0.15	0.15	ND	0.16
Thallium	2.2	2.2	ND	2.4
Thorium	1.5	1.5	ND	1.6
Thulium	ND	ND	ND	ND
Tin	14	14	10	15
Titanium*	140	140	830	150
Tungsten	0.74	0.74	ND	0.80
Uranium	1.3	1.3	ND	1.4
Vanadium*	4.5	4.0	650	8.7
Ytterbium	ND	ND	ND	ND
Yttrium	3.0	2.7	ND	3.2
Zinc*	160	130	180	150
Zirconium	14	9.1	20	10

*Analysis performed by ICPES.
**Analysis performed by AAS.
***Analysis performed by FPD/GC.
ND - not detected.
aEb = a x 10^b

†Ultimate analytical result.
††Method 6 analytical result.
†††Includes particulate, impinger and oil analyses.

mass of trace elements from the process. Cyclone dust, also a solid waste stream, is a second vehicle for discharge of trace elements from the gasifier. The ultimate fate of trace elements carried from the process in the solid waste streams is a function of the method of disposal. For example, trace elements in the gasifier ash and cyclone dust may enter the environment as a result of leaching by run-off waters from surface disposal sites or by leaching from landfills into ground waters.

The ash pan water, because of its contact with the gasifier ash, is another vehicle for discharge of trace elements from the gasifier. The concentration of trace elements in the ash pan water is dependent upon the form of the element in the gasifier ash, the length of time the ash is in contact with the water, and various physical characteristics of the ash (e.g., particle size).

Two other streams, the product gas and ESP oil, are vehicles for the transport of trace elements, but are not discharge streams from the process. Any trace elements borne by these streams can, however, be released to the environment in the discharges from downstream combustion processes.

Data on elemental distribution in discharge streams from several low- and medium-Btu coal gasification proceses have been generated as a result of similar source test and evaluation programs (4, 12).

5.3.2 Guidelines for Evaluation of Elemental Behavior

Three factors can generally be expected to influence the probable behavior of an element in a coal gasification system:

- the reactivity of the element,
- the elemental boiling point, and
- the temperature to which the element is exposed in the system.

Based on these factors, several general statements may be made that describe the behavior of elements:

- Nonvolatile elements or elements which do not react to form volatile compounds tend to remain in the mineral fraction of the coal ash and are discharged primarily in the gasifier bottom ash or wastewaters which have been in contact with the gasifier bottom ash.

- Moderately volatile trace elements can vaporize in the gasifier and condense by deposition upon available aerosol material or by nucleation. These elements, while found in the gasifier bottom ash, can also appear at increased concentrations in the solid wastes or organic condensates removed from the product gas by downstream gas clean-up systems.

- Volatile elements or elements which react to form volatile compounds generally remain in the product gases, and can be emitted to the environment in the emissions from product gas combustion.

Such elemental behavior was observed during characterization of single-stage gasification processes (4, 12), at which time certain criteria for evaluation of volatility were established. Using these criteria, elements were considered to exhibit volatile behavior if 25 percent or more of the total mass of the element discharged was emitted in the product gas. Elements were considered to exhibit moderately volatile behavior if 25 percent or more of their total mass was discharged in solid wastes or organic condensates from the product gas, and less than 25 percent of their total mass in the product gas.

Elements that do not discharge 25 percent or more of their total mass in either the product gas stream or solid matter borne in the product gas (e.g., cyclone dust or ESP oil) are considered to exhibit non-volatile behavior.

5.3.3 Elemental Distribution

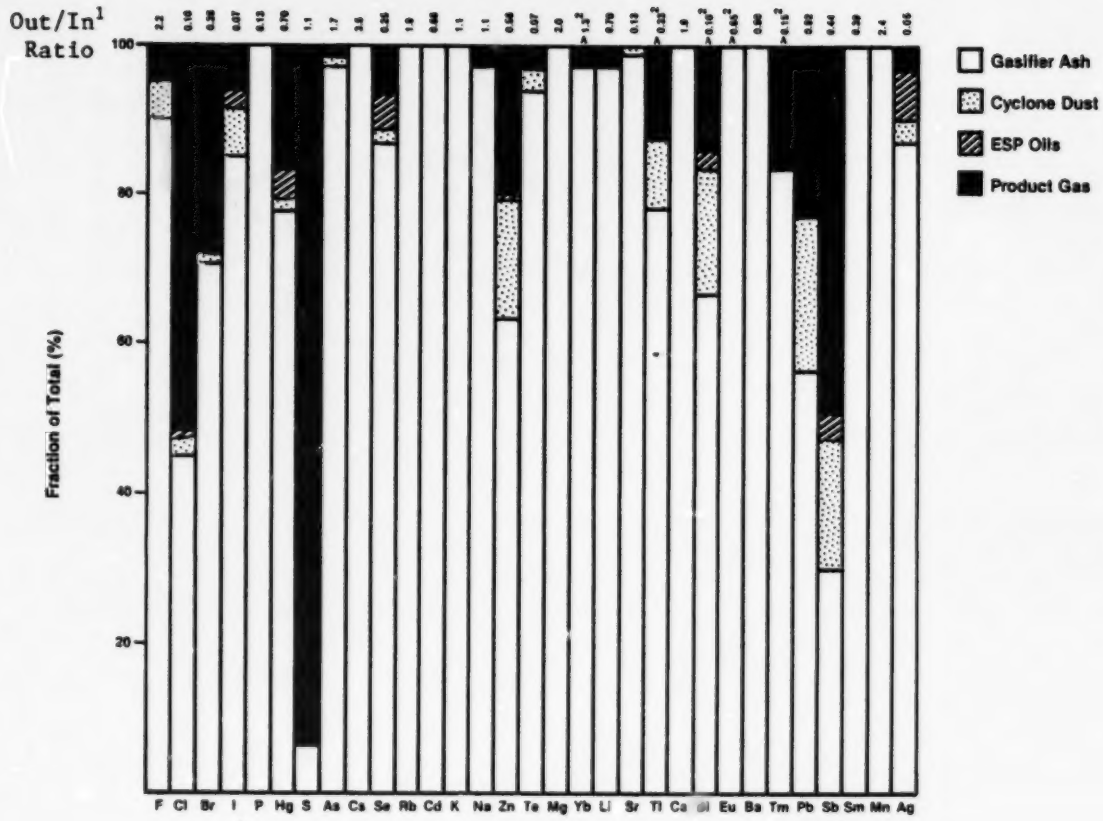
The distribution of minor and trace elements in the product, by-product, and discharge streams from the gasification process were calculated from the elemental mass flow rates of the respective streams. Figures 8 and 9 present the elemental distribution in the product, by-product, and discharge streams of the gasification process as a percent of the total mass of the element discharged. The elements are ordered according to ascending elemental boiling point. The ratio of the element in the product and discharge streams to the sum of the element in the coal is presented at the top of each bar.

Five elements have more than 25 percent of their total mass in the combined product gas and may be considered to exhibit volatile behavior. These elements are antimony, bromine, chlorine, sulfur, and tin. The vast majority of elements exhibit nonvolatile behavior and are discharged primarily in the gasifier ash. Of the 65 elements for which analytical data allowed an evaluation of elemental behavior, 57 are found primarily in the gasifier bottom ash and 43 of these have 95 percent or more of their mass discharged in the gasifier bottom ash.

While bismuth, lead, and zinc are discharged primarily in the bottom ash, 30 to 45 percent of the total mass discharged is found in the cyclone dust, ESP oil, and product gas. Tin, mentioned above as having more than 25 percent of its discharged mass in the product gas, is actually distributed almost equally across the bottom ash, cyclone dust, and product gas.

5.3.4 Elemental Enrichment

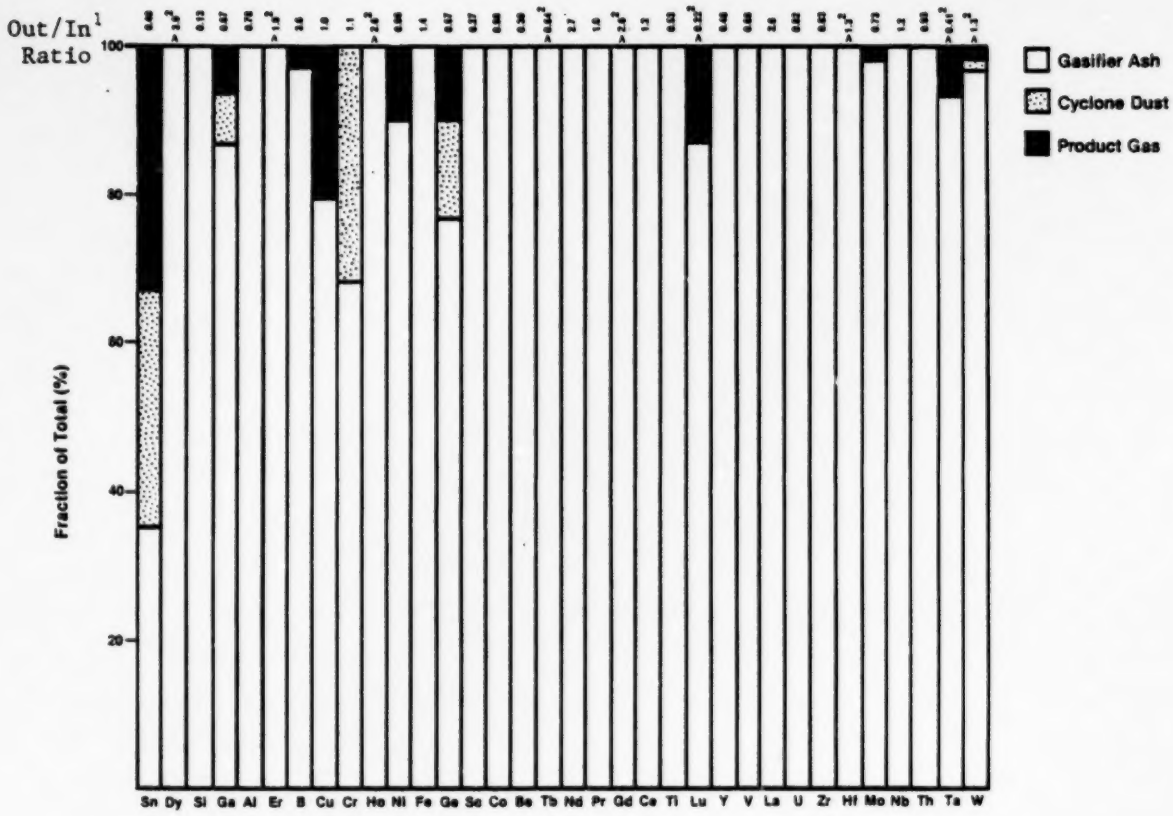
Another approach to evaluation of elemental behavior in the gasification process is the use of elemental concentration quotients. A concentration quotient is defined here as the ratio of the concentration of an element in a specific stream to the concentration of that same element in the coal, according to the following equation:



[1]Out/in ratio is calculated as $\frac{\text{total mass flow out}}{\text{total mass flow in (coal)}}$

[2]Concentration in coal is below the detection limit; total mass flow for coal is calculated as the detection limit concentration x flow rate.

Figure 8. Elemental distribution ordered by increasing elemental boiling point (up to 2212°C) - gasification process.



[1]Out/in ratio is calculated as $\frac{\text{total mass flow out}}{\text{total mass flow in (coal)}}$.

[2]Concentration in coal is below the detection limit; total mass flow for coal is calculated as the detection limit concentration x flow rate.

Figure 9. Elemental distribution ordered by increasing elemental boiling point (2270 to 5927°C) - gasification process.

$$\text{Concentration Quotient} = \frac{\text{Concentration of Element in Specific Stream}}{\text{Concentration of Element in Coal}}$$

Table 14 presents the concentrations and concentration quotients for elements in the gasifier ash, cyclone dust, and ESP oil. For the purpose of this discussion, concentrations and concentration quotients are also presented for the ash mineral fraction of each stream. The ESP oil is a by-product of gasification at UMD and is combusted in a boiler. However, other applications might increase the possibility of release of components in the ESP oil to the environment. For this reason, the ESP oil 's included with the wastes from the process for this study of elemental enrichment.

Elements enter the gasifier in the feed coal. The bulk of the carbonaceous material in the coal, as well as many volatile components, react during the gasification process to form gaseous products, while the bulk of the inorganic elemental material remains in the ash mineral fraction from the coal. If elemental enrichment is due to nothing more than the concentration of an element in the ash mineral fraction because of the loss of mass of carbonaceous and volatile organic components, then the change in elemental concentration of the element would be equal to the change of concentration of the ash mineral fraction in a stream.

However, due to various chemical or physical characteristics (e.g., boiling point, reactivity, native chemical form, etc.) some of the elements appear in waste streams at concentrations different from that which might be expected as a result of changes in the concentration of the ash mineral fraction (i.e., their concentration quotients, calculated from the equation given above, are greater or smaller than the concentration quotients calculated for the ash mineral fraction). If their concentration quotient is greater than that for the ash mineral fraction, they are considered to be enriched with respect to the ash mineral fraction. Conversely, if their concentration quotient is smaller, they are considered to be depleted with respect to the ash mineral fraction.

TABLE 14. FOSTER WHEELER/STOIC TWO-STAGE GASIFIER - ELEMENTAL CONCENTRATIONS (MASS/MASS) AND CONCENTRATION QUOTIENTS (BASED ON COAL) FOR MAJOR PROCESS STREAMS

	Coal	Gasifier Ash		Cyclone Dust		ESP oils	
Element	(μg/g)	(μg/g)	Q*	(μg/g)	Q*	(μg/g)	Q*
Aluminum	1.3 E4	7.8 E4	6	2.6 E4	2	54	(0.01)
Antimony	<0.2	<0.2	1	19	95	0.2	1
Arsenic	1.8	24	13	31	17	0.82	0.45
Barium	480	3300	6.9	320	0.7	5.2	0.01
Beryllium	0.3	0.9	3	0.8	2.7	ND	—
Bismuth	**	<0.1	0.5	4	20	0.03	0.2
Boron	25	690	28	98	4	<1	0.04
Bromine	2	3	1.5	7	3.5	0.1	0.05
Cadmium	1	5	5	3	3	ND	—
Calcium	3350	5.0 E4	15	1.2 E4	3.6	30	(0.01)
Cerium	11	99	9	28	2.5	0.06	(0.01)
Cesium	0.3	8	27	0.7	2.3	ND	—
Chlorine	27	10	0.37	86	3.2	0.3	0.01
Chromium	5.2	42	8	20	3.8	<0.1	0.02
Cobalt	1.6	12	7.5	4.3	2.7	<0.6	0.4
Copper	4.8	32	6.6	22	4.6	0.16	0.03
Dysprosium	**	6	30	4	20	ND	—
Erbium	**	3	15	0.8	4	ND	—
Europium	**	1	5	1	5	ND	—
Fluorine	7	110	16	>1000	>143	4	0.6
Gadolinium	**	4	20	2	10	ND	—
Gallium	5	23	4.6	280	56	0.07	0.01
Germanium	≤0.2	0.7	3.5	19	95	≤0.02	0.1
Gold	**	ND	—	ND	—	ND	—
Hafnium	**	2	10	≤2	10	ND	—
Holmium	**	4	20	1	5	ND	—
Iodine	≤0.4	0.3	1	4	10	0.06	0.15
Iridium	**	ND	—	ND	—	ND	—
Iron	3600	4.0 E4	11	1.2 E4	3.3	170	0.05
Lanthanum	9	180	20	20	2.2	.05	(0.01)
Lead	3	12	4	870	290	0.4	0.13
Lithium	12	64	5.3	27	2.3	0.03	(0.01)
Lutetium	**	0.3	1.5	ND	—	ND	—
Magnesium	760	1.2 E4	16	2400	3.2	<5.4	(0.01)
Manganese	24	440	18	48	2	0.54	0.02
Mercury	<0.07	0.30	4.3	0.75	10.7	0.16	2.3
Molybdenum	2.9	16	5.5	7.6	2.6	0.65	0.2
Neodymium	0.9	19	21	2	2.2	ND	—
Nickel	4.6	31	6.7	16	3.5	<0.3	0.2
Niobium	4	38	9.5	10	2.5	ND	—
Osmium	**	ND	—	ND	—	ND	—

(Continued)

TABLE 14. (Continued)

Element	Coal (μg/g)	Gasifier Ash (μg/g)	Gasifier Ash Q*	Cyclone Dust (μg/g)	Cyclone Dust Q*	ESP oils (μg/g)	ESP oils Q*
Palladium	**	ND	—	ND	—	ND	—
Phosphorus	>1000	>1000	1	>1000	1	3	(0.01)
Platinum	**	ND	—	ND	—	ND	—
Potassium	950	8200	8.6	2700	2.8	28	0.03
Praseodymium	2	16	8	5	2.5	≤0.01	(0.01)
Rhenium	**	ND	—	ND	—	ND	—
Rhodium	**	ND	—	ND	—	ND	—
Rubidium	4	59	15	9	2.2	0.02	(0.01)
Ruthenium	**	ND	—	ND	—	ND	—
Samarium	2	6	3	4	2	ND	—
Scandium	1	2	2	1	1	<0.01	(0.01)
Selenium	0.36	0.6	1.7	2.6	7.2	<0.3	0.8
Silicon	>1000	>1000	1	>1000	1	4	(0.01)
Silver	0.8	<0.3	0.4	<2	2.5	0.2	0.25
Sodium	180	1500	8.3	690	3.8	49	0.27
Strontium	>1000	>1000	1	760	0.8	0.4	(0.01)
Sulfur	5200	2800	0.53	1.0 E4	1.9	2400	0.46
Tantalum	**	0.6	3	ND	—	ND	—
Tellurium	0.4	0.2	0.5	1	2.5	ND	—
Terbium	**	1	5	0.8	4	ND	—
Thallium	**	0.4	2	12	60	ND	—
Thorium	4	29	7.3	8	2	ND	—
Thulium	**	0.2	1	ND	—	ND	—
Tin	0.4	0.5	1.2	77	192	0.04	0.1
Titanium	440	1800	4.1	780	1.8	3.3	(0.01)
Tungsten	**	2	10	4	20	ND	—
Uranium	3	19	6.3	7	2.3	ND	—
Vanadium	9.7	66	6.8	24	2.5	2.6	0.27
Ytterbium	**	2	10	ND	—	ND	—
Yttrium	14	50	3.6	16	1.1	ND	—
Zinc	5.1	15	2.9	620	121	0.71	0.14
Zirconium	31	200	6.4	55	1.8	0.08	(0.01)
Ash minerals	9.51 E4	7.77 E5	8.2	2.7 E5	2.8	<1800	0.02

*Concentration quotient = $\frac{\mu g \text{ element/g stream}}{\mu g \text{ element/g coal}}$ or $\frac{\mu g \text{ ash/g stream}}{\mu g \text{ ash/g coal}}$

**Not detected in coal at levels equal to detection limit for spark source mass spectrometry. Value set at detection limit (0.2 μg/g) for calculation of concentration quotient (Q). Calculated value presented as concentration quotient for these elements can be considered as an apparent minimum concentration quotient.

ND = Not detected at levels equal to detection limit of technique.

— = Quotient not calculated for elements not detected.

< = AA/ICPES detection limit.

≤ = SSMS value.

> = Major component (>1000 ppm) by SSMS analysis.

(0.01) = For ESP oil, calculated quotient is less than 0.01.

This relationship may be expressed as:

$$\text{Enrichment Factor} = \frac{\text{Concentration Quotient of Element in Stream}}{\text{Concentration Quotient of Ash Minerals in Stream}}$$

An enrichment factor greater than one is indicative of enrichment with respect to ash minerals; conversely, a factor less than one is indicative of depletion.

Many volatile elements become enriched with respect to the ash mineral fraction in aerosolized organic or particulate matter entrained in gaseous process streams. The theoretical mechanism by which this enrichment may occur has been described previously, in Section 5.3.

The elemental concentration quotients of selected minor and trace elements in the gasifier ash, cyclone dust, and ESP oil, are presented graphically in Figures 10 through 15. The elements are listed in order of ascending elemental boiling point.

The gasifier bottom ash is the primary vehicle for elemental discharge of the majority of elements. However, only eleven elements detected in the coal and also in the gasifier ash were found to be enriched with respect to the ash mineral fraction in the gasifier ash stream. These elements were:

Arsenic	Fluorine	Manganese
Boron	Iron	Neodynium
Calcium	Lanthanum	Rubidium
Cesium	Magnesium	

An additional fourteen elements can possibly be considered to be enriched in the gasifier ash because they were found in the gasifier ash and had not been found at detectable levels in the feed coal. These were:

Bismuth	Hafnium	Thallium
Dysprosium	Holmium	Thulium
Erbium	Lutetium	Tungsten
Europium	Tantalum	Ytterbium
Gadolinium	Terbium	

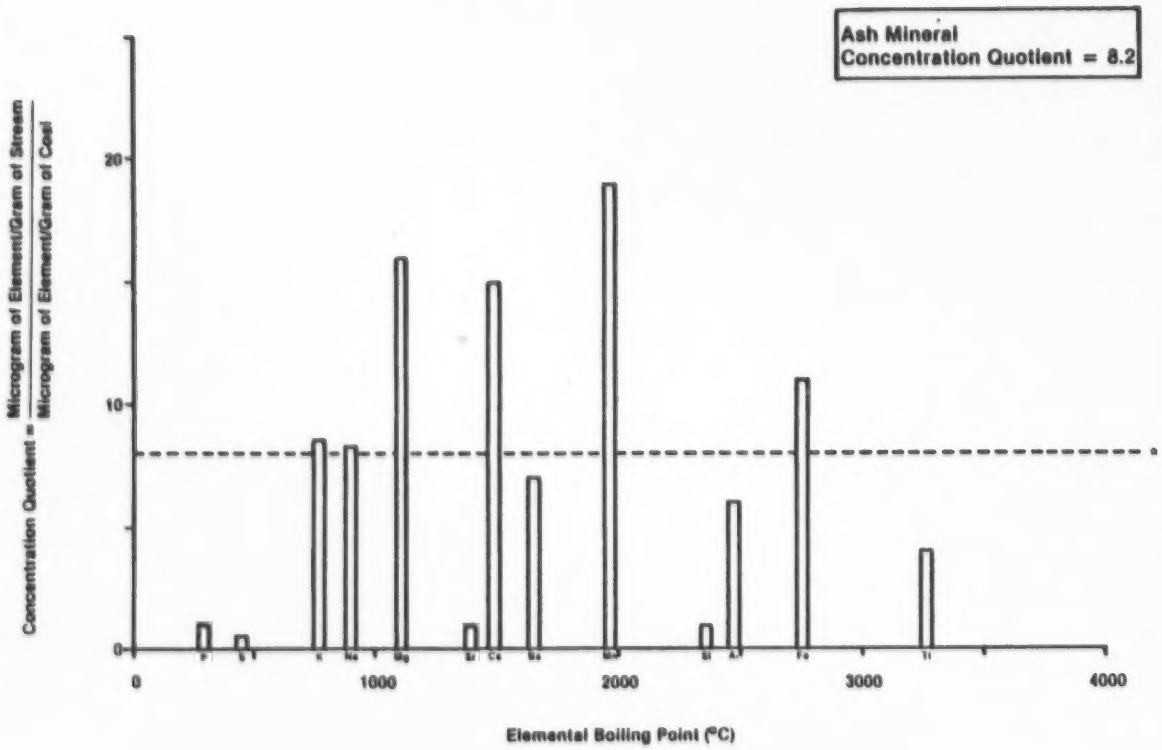


Figure 10. Concentration quotients for major elements in gasifier ash.

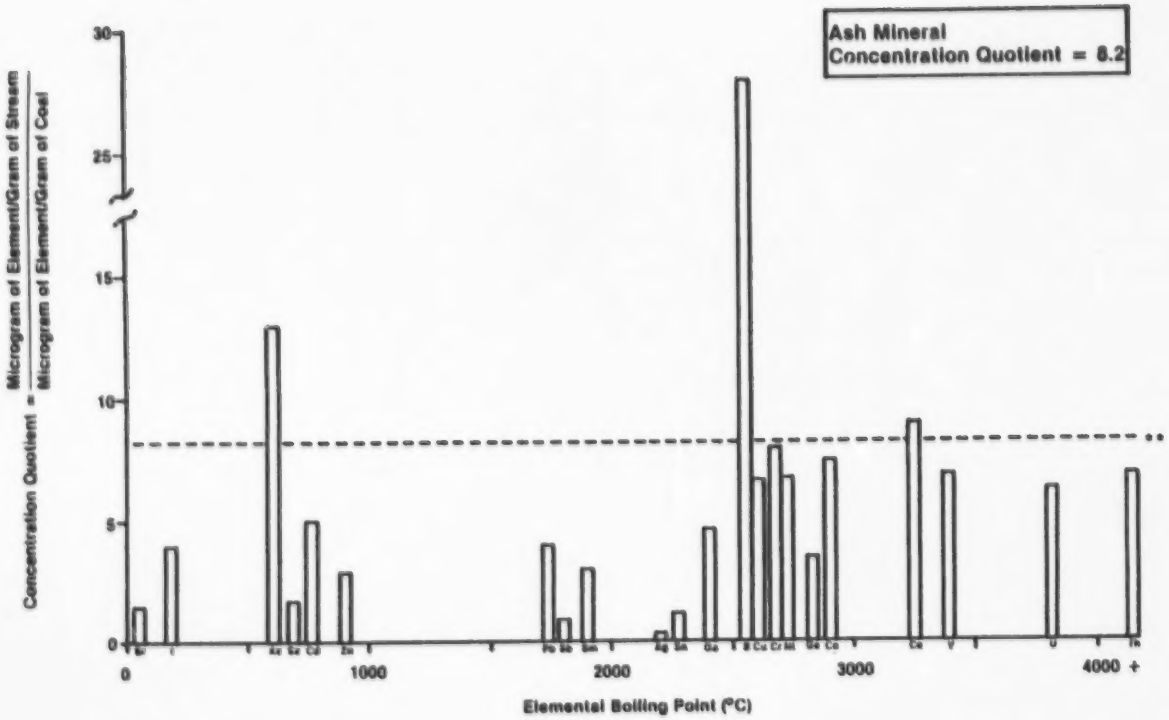


Figure 11. Concentration quotients for trace elements in gasifier ash.

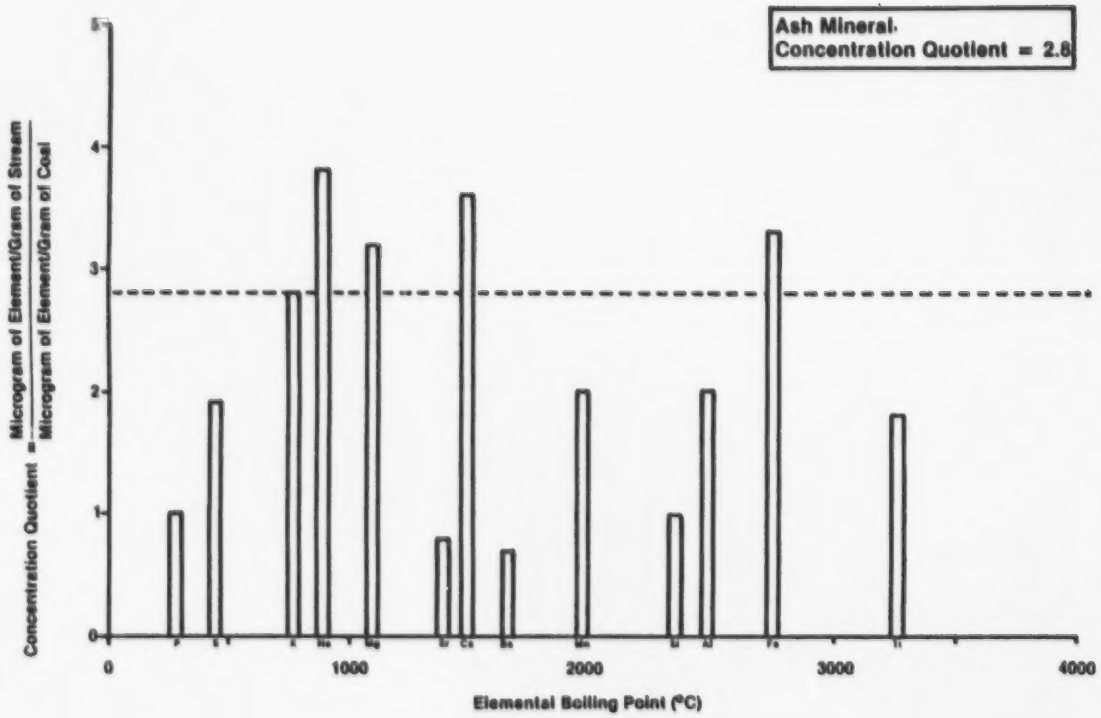


Figure 12. Concentration quotients for major elements in cyclone dust.

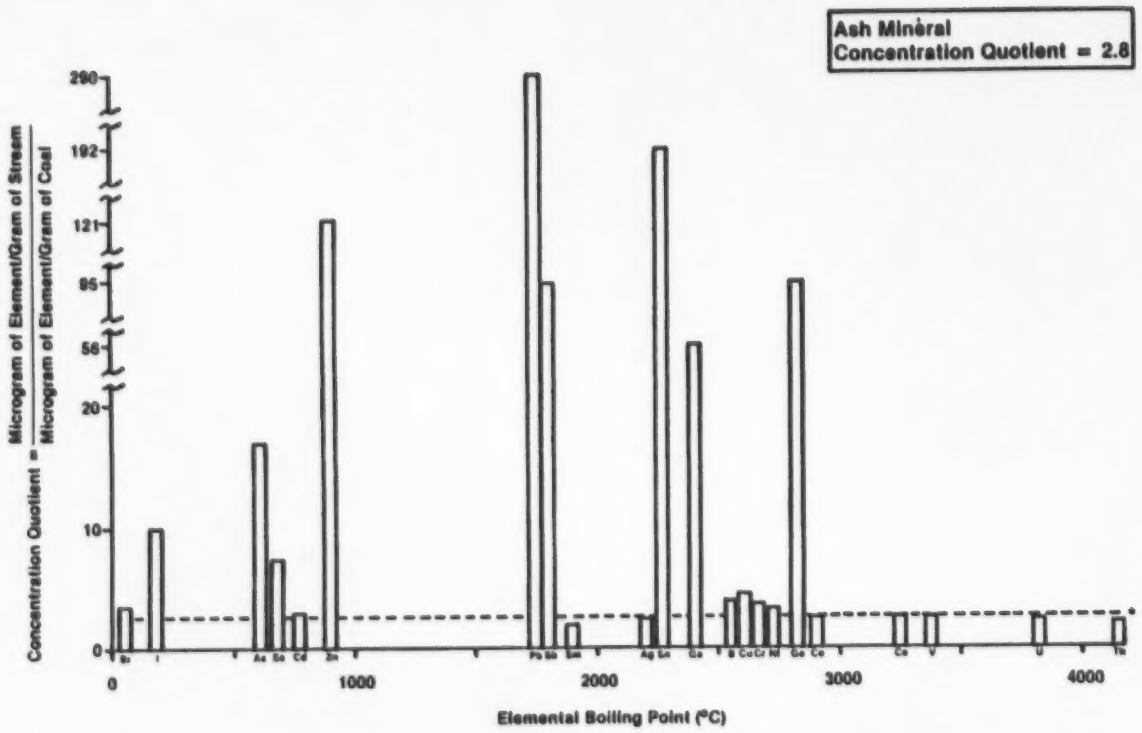


Figure 13. Concentration quotients for trace elements in cyclone dust.

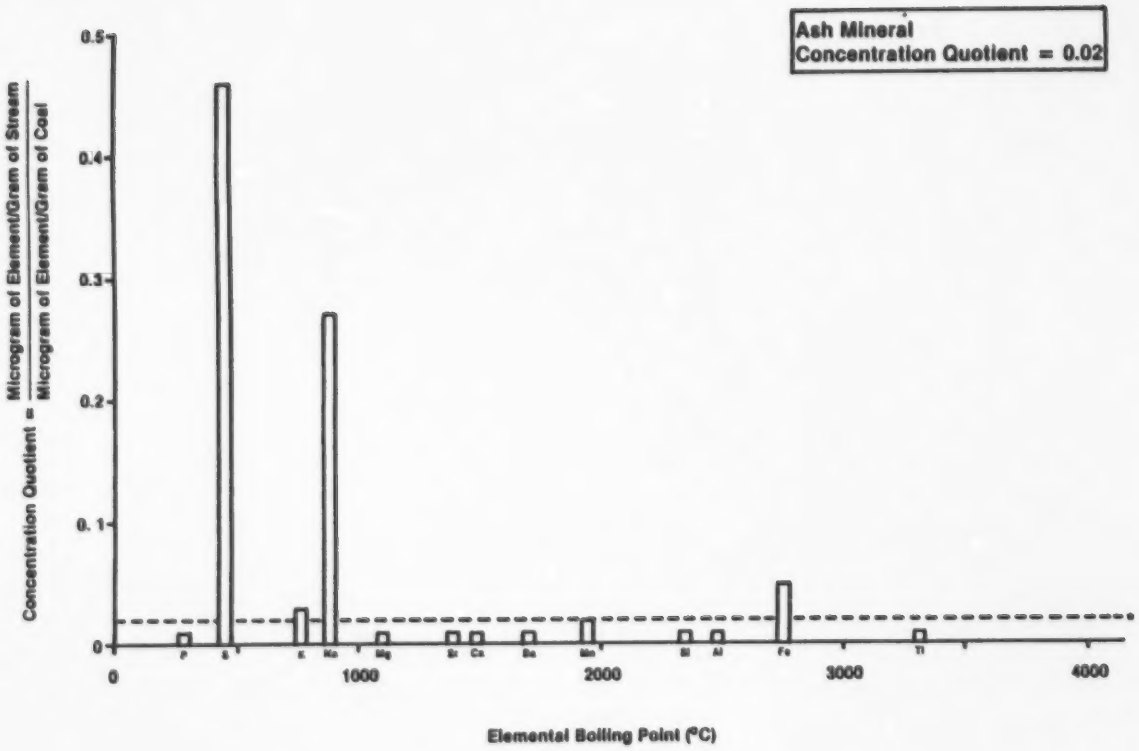


Figure 14. Concentration quotients for major elements in ESP oil.

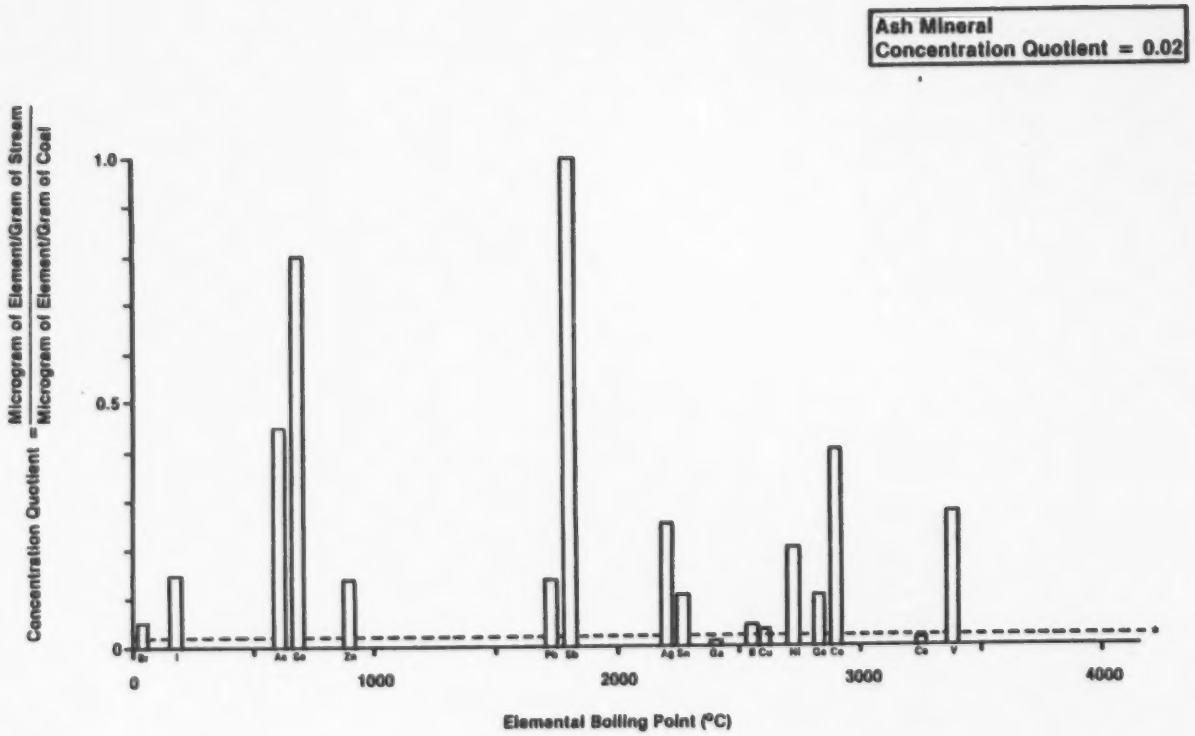


Figure 15. Concentration quotients for trace elements in ESP oil.

Based on the criteria established for the evaluation of elemental volatility (Section 5.3.2), all of these elements could be considered to be non-volatile and therefore would not be expected to be depleted in the gasifier ash. Four more elements, also considered to be non-volatile according to the criteria for assessing volatility, were found to show concentration quotients only slightly higher than the concentration quotient for the ash mineral fraction in the gasifier ash. These elements were cerium, niobium, potassium, and sodium. All the other elements (see Table 14), including many elements which, according to the criteria would be considered to be non-volatile, were found to be depleted in the gasifier ash with respect to the ash mineral fraction.

The possible influence of other factors such as reactivity or chemical form (e.g., the presence of organometallic compounds in the coal or the formation of similar complex materials in the volatile organic stream at the lower temperature encountered in the volatilization zone of a two-stage gasifier) may be indicated by the behavior of these elements.

Ten elements exhibited significant enrichment with respect to the ash mineral fraction of the cyclone dust. These were:

Antimony	Germanium	Mercury
Arsenic	Iodine	Tin
Fluorine	Lead	Zinc
Gallium		

An additional ten elements were found in the cyclone dust which were not found at detectable levels in the coal.

Bismuth	Gadolinium	Terbium
Dysprosium	Hafnium	Thallium
Erbium	Holmium	Tungsten
Europium		

Only lead and zinc could be considered to be moderately volatile to volatile based upon criteria for evaluation of volatility according to elemental

distribution (percentage of mass discharged in a stream). Antimony and tin were considered to be volatile according to the same criteria.

Thirteen elements were found in the cyclone dust at concentration quotients equal to or only slightly higher than the concentration quotient for the ash mineral fraction. These were:

Boron	Chromium	Nickel
Bromine	Copper	Potassium
Cadmium	Iron	Selenium
Calcium	Magnesium	Sodium
Chlorine		

All other elements (see Table 14) showed depletion with respect to the ash mineral fraction of the cyclone dust.

While a number of elements appeared to be enriched with respect to the ash mineral fraction of the ESP oil, the apparent elemental enrichment may be an artifact of the extremely low ash mineral content of the ESP oil, or may be due to some factor or factors unrelated to elemental boiling points. Mercury was present in the ESP oil at a concentration (mass/mass) exceeding its concentration in the feed coal. The concentration of antimony in the ESP oil was essentially identical with its concentration in the feed coal, and the concentration of selenium was within 20 percent of its concentration in the feed coal. All other elements in the ESP oil were found at concentrations significantly lower than their concentrations in the feed coal.

5.4 Extractable Organics

Extractable organics in product gas and discharge streams were characterized by total organic loading and by gas chromatographic analyses. The total organic loading is the sum of TCO and GRAV values. Table 15 summarizes the results of the organic loadings for the process and discharge streams.

TABLE 15. EXTRACTABLE ORGANICS SUMMARY

Stream	Extractable Organics	
	Concentration (TCO & GRAV)	Mass Flow (g/sec)
Ash Pan Water	1.0 E3* μg/L	9.0 E-6
Cyclone Dust	1.2 E2 μg/g	2.4 E-5
Gasifier Ash	1.0 E2 μg/g	3.5 E-3
ESP Oil	9.3 E5 μg/g	3.7 E0
Combined Product Gas	4.0 E6 μg/Nm^3	3.8 E0
Aerosols**	2.1 E5 μg/Nm^3	2.0 E-1
Vapors	3.8 E6 μg/Nm^3	3.6 E0
Cleaned Top Product Gas	7.4 E6 μg/Nm^3	4.1 E0
Aerosols**	1.5 E5 μg/Nm^3	8.3 E-2
Vapors	7.2 E6 μg/Nm^3	4.0 E0
Raw Top Product Gas	1.3 E7 μg/Nm^3	7.0 E0
Aerosols**	7.4 E6 μg/Nm^3	4.1 E0
Vapors	5.2 E6 μg/Nm^3	2.9 E0
Cleaned Bottom Product Gas	8.9 E4 μg/Nm^3	3.9 E-2
Raw Bottom Product Gas	1.2 E4 μg/Nm^3	7.6 E-3
Combustion Emissions from Product Gas Boiler	2.7 E1 μg/Nm^3	1.3 E-4
Combustion Emissions from Boiler No. 3 Firing ESP Oil	2.7 E3 μg/Nm^3	1.1 E-2

*aEb = a x 10^b.
**That portion of aerosol loading extractable with methylene chloride and diethyl ether.

As indicated in the table, the concentrations of extractable organics in the gasifier ash and cyclone dust are comparable. Approximately 98 percent (mass flow) of the extractable organics found as aerosols in the raw top gas are removed by the ESP. The mass flows of the extractable organics in the ESP oil, the cleaned top gas, and the combined product gas are essentially the same. However, the concentration of extractable organics in the combustion emissions from Boiler No. 3 firing ESP oil is about two orders of magnitude higher than in the emissions from the product gas boilers.

Extracts of composited samples of the gasifier ash, ash pan water, cyclone dust, ESP oil to Boiler No. 3, combined product gas, and combustion emissions from the product gas boilers and Boiler No. 3 were characterized by GC/MS analysis. Priority pollutants were identified and quantitated to provide data for EPA's Effluent Guideline Division. Table 16 presents the analytical results for priority pollutants identified in the streams. In addition, major peaks were identified and quantitated against d_{10} anthracene. A list of the extractable organics of each sample identified by GC/MS is presented in Tables B-52 to B-58 (Appendix B). The data presented in these tables indicate that the majority of compounds analyzed by GC/MS are identified. Cyclone dust had the lowest percentage of identified mass (34 percent).

Table 17 gives the mass flows of priority pollutants found in the product and emissions streams on a mass flow basis. The combined product gas and ESP oil contain the greatest mass flow of priority pollutants of any stream leaving the gasification process; however, both streams are combusted and are not discharged directly. The mass flow of the priority pollutants identified in the emissions from combustion of product gas is 0.15 percent of the product gas loading, as shown below:

$$\frac{1.1E2\ \mu g/sec\ \text{emissions from product gas boiler}}{7.2E4\ \mu g/sec\ \text{combined product gas}} \times 100 = 0.15\%$$

For the ESP oil fired in Boiler No. 3, the loading of priority pollutants in the combustion emissions was 0.02 percent of that in the ESP oil:

TABLE 16. CONCENTRATION OF PRIORITY POLLUTANTS IDENTIFIED IN PRODUCT AND DISCHARGE STREAMS - UMD

Compound	Gasifier Ash (μg/g)	Ash Pan Water (μg/L)	Cyclone Dust (μg/g)	ESP Oil to Boiler #3 (μg/g)	Combined Product Gas (μg/Nm^3)	Emissions from Product Gas Boiler (μg/Nm^3)	Emissions from Boiler No. 3 (μg/Nm^3)
Phenol	ND	3.3	ND	2400	4200	3.7	30
2,4-dimethylphenol	ND	ND	ND	ND	2.4E4	ND	ND
Naphthalene	0.01	0.33	0.15	310	7800	9.4	16
1-methylnaphthalene	ND	ND	0.01	540	7500	1.4	1.8
2-methylnaphthalene	ND	ND	0.01	370	6300	1.2	1.7
Dimethylnaphthalene	ND	ND	0.05	2500	2.3E4	1.4	1.3
Phenanthrene	ND	ND	0.01	320	310	0.32	0.72
Anthracene	ND	ND	ND	240	220	ND	ND
Fluorene	ND	ND	ND	320	29	0.36	0.48
Pyrene	ND	ND	0.04	ND	120	0.14	0.46
Benzo(a)anthracene	ND	ND	ND	240	ND	ND	ND
Bis(2-ethylhexyl) phthalate*	0.04	6.7	ND	20	1200	5.0	20

*Probable artifact of sample handling.

TABLE 17. MASS FLOW OF PRIORITY POLLUTANTS IN PRODUCT AND DISCHARGE STREAMS - UMD*

	Product Streams		Discharge Streams					
Compound	ESP Oil to Boiler No. 3	Combined Product Gas	Cyclone Dust	Gasifier Ash	Ash Pan Water	Combustion Emissions from Product Gas Boiler	Combustion Emissions from Boiler No. 3	Σ Emissions
Phenol	6.0E5	3990	ND	ND	0.03	17.3	125	142
2,4-dimethylphenol	ND	2.4E4	ND	ND	ND	ND	ND	ND
Naphthalene	7.8E4	7410	0.03	0.35	0.003	43.9	66.7	111
1-methylnaphthalene	1.3E5	7125	0.002	ND	ND	6.54	7.5	14
2-methylnaphthalene	9.2E4	5990	0.002	ND	ND	5.60	7.1	12.7
Dimethylnaphthalene	6.2E5	2.2E4	0.01	ND	ND	6.54	5.4	12
Phenanthrene	8.8E4	295	.002	ND	ND	1.49	3	4.5
Anthracene	6.0E4	209	ND	ND	ND	ND	ND	ND
Fluorene	8.0E4	27	ND	ND	ND	1.68	2.0	3.68
Pyrene	ND	114	0.008	ND	ND	0.65	1.92	2.58
Benzo(a)anthracene	6.0E4	ND	ND	ND	ND	ND	ND	ND
Bis(2-ethylhexyl) phthalate	5000	1140	ND	1.4	0.06	23.4	83.4	108
TOTAL	1.8E6	7.2E4	0.054	1.75	0.093	107	302	411

*All mass flows are given as μg/sec.
ND = not detected.

$$\frac{3.0E2\ \mu g/sec\ emissions\ from\ Boiler\ No.\ 3}{1.86E6\ \mu g/sec\ ESP\ oil} \times 100 = 0.02\%$$

Noticeably absent from the analytical results are the polynuclear aromatic compounds such as acenaphthalene, benzo(a)pyrene, and fluoranthene. These compounds were not detected in any of the product or discharge streams at the detection limits of the technique.

Analyses by gas chromatography-Hall electrolytic conductivity detection (GC-HECD) of extracts of the combined product gas, ESP oil to Boiler No. 3, and the combustion emissions from the product gas boilers and Boiler No. 3 firing ESP oil are summarized in Table 18.

TABLE 18. RESULTS OF GC-HECD ANALYSIS FOR ORGANIC SULFUR, NITROGEN AND HALOGEN IN FEED AND COMBUSTION STREAMS* - UMD

	Product Gas Boilers		ESP Oil Boiler	
	Feed	Emissions	Feed	Emissions
Organic Sulfur Species	3.94E4	2.07E2	1.41E6	1.38E2
Organic Nitrogen Species	2.32E4	8.12E0	1.65E5	1.63E1
Organic Halogen Species	1.15E2	ND	ND	4.79E0

*Mass flow in μg/sec. Results are for sulfur, nitrogen, and halogen atoms bound to an extractable organic component.
ND = Not detected.

The levels of organic sulfur, nitrogen and halogen species in the combustion emissions relative to the levels in the feed streams indicate a significant destruction of the organic molecules during combustion. The apparent generation of a small (<5 μg/sec) flow of organic halogen during combustion of ESP oil is considered to be an artifact of the sampling and analytical procedures used (non-concurrent sampling and analyses of gaseous and heavy organic liquid streams).

The total organic sulfur for ESP oil to Boiler No. 3 is about two orders of magnitude greater than the concentration of organic sulfur in the combined product gas. The emissions of organic sulfur for both boilers is essentially the same. Sulfur present in both feedstocks may be converted to inorganic sulfur species and measured as emissions of sulfur oxides. Nitrogen present in the form of organic nitrogen species in the combined product gas and ESP oil is combusted in the boilers and may be emitted as nitrogen oxide. Organic halogen present in the feed streams may be emitted as an inorganic halogen complex. A further discussion of nitrogen and sulfur oxides is found in Section 5.5. Results of the GC-HECD analyses for all discharge streams are found in Tables B-48 through B-51 (Appendix B).

5.5 Gas Compositions

Eight gaseous process and emission streams were characterized for concentrations of major gases, hydrocarbons, sulfur species, moisture, extractable organics, ammonia, cyanide, and aerosols and particulates. Also, emissions of nitrogen and sulfur oxides were measured in the combustion streams. Tables 19 to 22 present the analytical results. Results of the individual analyses are presented in Tables B-39 through B-47 and Table B-67 (Appendix B).

The C_1 through C_5 hydrocarbons present in the combined product gas appeared totally destroyed upon combustion in the product gas boilers. The mass flow rate for C_6 hydrocarbons appears to be higher in the emissions from the product gas boilers (4.7E8$\pm$4.2E8 μg/min) than in the combined product gas (5.0E7$\pm$1.2E7 μg/min). However, the emissions mass flow rate is based upon analysis of only two samples. The first sample, collected at 3:40 p.m. on February 24, 1981 and subjected to a single analysis, was found to contain 784 ppmv of C_6 hydrocarbons. The second sample was collected at 8:15 p.m. on the same date. Duplicate analyses of this sample resulted in C_6 concentrations of 179 and 180 ppmv. The value reported for C_6 flow rate in the emissions is calculated based on the analyses of both samples and thus shows a large standard deviation.

TABLE 19. AVERAGE COMPOSITION AND COMPONENT MASS FLOW OF THE COMBINED PRODUCT GAS AND COMBUSTION EMISSIONS FROM THE PRODUCT GAS BOILERS - UMD*

Parameter	Combined Product Gas		Combustion Emissions from Product Gas Boilers	
	$\mu g/Nm^3 \pm \sigma$	$\mu g/min \pm \sigma$	$\mu g/Nm^3 \pm \sigma$	$\mu g/min \pm \sigma$
CO_2	7.6 E7 ± 1.1 E7	4.3 E9 ± 6.2 E8	1.5 E8 ± 3.6 E6	4.2 E1 ±1.0 E9
H_2	1.3 E7 ± 2.0 E6	7.4 E8 ± 1.1 E8	3.3 E4 ± 4.1 E4	9.2 E6 ±1.1 E7
O_2 + Ar	9.8 E7 ± 2.5 E6	5.5 E9 ± 1.4 E8	1.6 E8 ± 5.2 E6	4.4 E10±1.4 E9
N_2	5.4 E8 ± 3.6 E7	3.0E10 ± 2.0 E9	9.3 E8 ± 4.6 E6	2.6 E11±1.2 E9
CO	3.2 E8 ± 2.3 E7	1.8E10 ± 1.3 E9	ND	ND
Moisture	7.1 E7 ± 6.3 E6	4.0 E9 ± 3.5 E8	1.4 E8 ± 3.3 E6	3.9 E10±9.2 E8
CH_4	1.2 E7 ± 2.4 E6	6.8 E8 ± 1.3 E8	ND	ND
C_2H_6	1.7 E6 ± 3.7 E5	9.6 E7 ± 2.1 E7	ND	ND
C_2H_4	2.9 E5 ± 7.6 E4	1.6 E7 ± 4.3 E6	ND	ND
C_3	1.3 E6 ± 2.7 E5	7.4 E7 ± 1.5 E7	ND	ND
C_4	7.8 E5 ± 1.7 E5	4.4 E7 ± 9.6 E6	ND	ND
C_5	6.2 E5 ± 1.3 E5	3.5 E7 ± 7.4 E6	ND	ND
C_6	8.8 E5 ± 2.2 E5	5.0 E7 ± 1.2 E7	1.7 E6 ± 1.5 E6	4.7 E8 ±4.2 E8
Benzene	2.4 E5 ± 2.5 E4	1.3 E7 ± 1.4 E6	<4.6 E2	<1.2 E5
Toluene	4.3 E5 ± 1.6 E5	2.4 E7 ± 9.1 E6	2.1 E4 ± 2.2 E4	5.8 E6 ±6.1 E6
Xylene	3.0 E5 ± 1.2 E5	1.7 E7 ± 6.8 E6	ND	ND
H_2S	1.0 E6 ± 1.1 E5	5.7 E7 ± 6.2 E6	ND	ND
COS	1.9 E5 ± 1.1 E4	1.0 E7 ± 6.2 E5	ND	ND
CH_3SH	4.3 E4 ± 1.1 E4	2.4 E6 ± 6.2 E5	ND	ND
C_2H_5SH	<4.8 E3 ± 2.3 E3	<2.7 E5 ± 1.3 E5	ND	ND
CS_2	<3.1 E3	<1.7 E5	ND	ND
C_4H_4S	<3.4 E3	<1.9 E5	ND	ND
NH_3	8.3 E5 ± 5.7 E4	4.7 E7 ± 3.2 E6	<4.3 E2	<1.2 E5
HCN	2.4 E5 ± 3.2 E4	1.3 E7 ± 1.8 E6	1.7 E3 ± 5.7 E1	4.7 E5 ±1.5 E4
SO_2	ND	ND	7.0 E5 ± 2.5 E4	1.9 E8 ±7.0 E6
NO_x (as NO_2)	NA	NA	5.1 E5 ± 1.3 E5	1.4 E8 ±3.6 E7
Extractable Organics†	4.0 E6	2.3 E8	2.7 E1	7.5 E3
Aerosol Organics#	2.0 E4	1.1 E6	ND	ND
Particulate	1.9 E5	1.1 E7	3.9 E4	1.0 E7

*Results presented as concentration in dry gas.
†Sum of TCO and GRAV values.
#That portion of aerosol extractable with methylene chloride and diethyl ether.
ND - not detected.
NA - not analyzed.

TABLE 20. AVERAGE COMPOSITION AND COMPONENT MASS FLOW OF THE TOP PRODUCT GAS - UMD*

Parameter	Raw Top Product Gas		Cleaned Top Product Gas	
	$\mu g/Nm^3 \pm \sigma$	$\mu g/min \pm \sigma$	$\mu g/Nm^3 \pm \sigma$	$\mu g/min \pm \sigma$
CO_2	6.7 E7 ± 8.1 E6	2.2 E9 ± 2.6 E8	7.2 E7 ± 6.5 E6	2.3 E9 ± 2.1 E8
H_2	1.3 E7 ± 1.1 E6	4.2 E8 ± 3.6 E7	1.3 E7 ± 1.7 E6	4.2 E8 ± 5.6 E7
O_2 + Ar	9.9 E6 ± 1.2 E6	3.2 E8 ± 3.9 E7	1.1 E7 ± 3.9 E6	3.6 E8 ± 1.2 E8
N_2	4.9 E8 ± 2.3 E7	1.6 E10 ± 7.5 E8	5.0 E8 ± 2.4 E7	1.6 E10 ± 7.9 E8
CO	3.2 E8 ± 1.1 E7	1.0 E10 ± 3.6 E8	3.2 E8 ± 1.1 E7	1.0 E10 ± 3.6 E8
Moisture	1.4 E8 ± 2.2 E7	4.6 E9 ± 7.2 E8	1.4 E8 ± 3.3 E6	4.6 E9 ± 1.0 E8
CH_4	2.4 E7 ± 2.1 E6	7.2 E9 ± 5.9 E7	2.0 E7 ± 4.8 E6	6.6 E8 ± 1.5 E8
C_2H_6	3.2 E6 ± 3.8 E5	1.0 E8 ± 1.2 E7	2.7 E6 ± 6.4 E5	8.9 E7 ± 2.1 E7
C_2H_4	6.0 E5 ± 3.3 E4	1.9 E7 ± 1.0 E6	3.8 E5 ± 2.4 E5	1.2 E7 ± 7.9 E6
C_3	2.5 E6 ± 1.7 E5	8.2 E7 ± 5.6 E6	2.2 E6 ± 4.9 E6	7.2 E7 ± 1.6 E8
C_4	1.5 E6 ± 1.0 E5	4.9 E7 ± 3.3 E6	1.3 E6 ± 2.8 E5	4.2 E7 ± 9.2 E6
C_5	1.1 E6 ± 7.7 E4	3.6 E7 ± 2.5 E6	9.7 E5 ± 2.3 E5	3.2 E7 ± 7.5 E6
C_6	1.6 E6 ± 1.2 E5	5.2 E7 ± 3.9 E6	1.3 E6 ± 3.3 E5	4.2 E7 ± 1.0 E7
Benzene	5.0 E5	1.6 E7	3.5 E5 ± 4.8 E5	1.1 E7 ± 1.5 E7
Toluene	7.4 E5	2.4 E7	9.5 E5 ± 3.3 E4	3.1 E7 ± 1.0 E6
Xylene	4.8 E5	1.5 E7	8.4 E5 ± 7.6 E4	2.7 E7 ± 2.5 E6
H_2S	1.0 E6 ± 4.2 E4	3.3 E7 ± 1.3 E6	1.0 E6 ± 5.6 E4	3.3 E7 ± 1.8 E6
COS	1.4 E5 ± 2.9 E3	4.6 E6 ± 9.5 E4	1.4 E5 ± 2.5 E3	4.6 E6 ± 8.2 E4
CH_3SH	7.9 E4 ± 1.1 E3	2.6 E6 ± 3.6 E4	7.7 E4 ± 4.3 E3	2.5 E6 ± 1.4 E5
C_2H_5SH	1.0 E4	3.3 E5	7.6 E3 ± 0	2.5 E5 ± 0
CS_2	<3.1 E3	<1.0 E5	<3.1 E3	<1.0 E5
C_4H_4S	3.4 E3	1.1 E5	<3.4 E3	<1.1 E5
SO_2	ND	ND	ND	ND
NH_3	1.7 E6 ± 1.6 E5	5.6 E7 ± 5.2 E6	1.5 E6 ± 3.9 E5	4.9 E7 ± 1.2 E7
HCN	2.8 E5 ± 3.2 E4	9.2 E6 ± 1.0 E6	2.5 E5 ± 4.6 E4	8.2 E6 ± 1.5 E6
Extractable Organics†	1.3 E7	4.2 E8	7.4 E6	2.4 E8
Aerosol Organics#	7.3 E6	2.4 E8	1.5 E5	4.9 E6
Particulate	1.2 E5	3.9 E6	3.1 E4	1.0 E6

*Results presented as concentration in dry gas.
†Sum of TCO and GRAV values.
#That portion of aerosol loading extractables with methylene chloride and diethyl ether.
ND - not detected.

TABLE 21. AVERAGE COMPOSITION AND COMPONENT MASS FLOW OF BOTTOM PRODUCT GAS - UMD*

Parameter	Raw Bottom Product Gas		Cleaned Bottom Product Gas	
	$\mu g/Nm^3 \pm \sigma$	$\mu g/min \pm \sigma$	$\mu g/Nm^3 \pm \sigma$	$\mu g/min \pm \sigma$
CO_2	1.1 E8 ± 5.8 E6	4.1 E9 ± 2.2 E8	9.2 E7 ± 1.3 E7	2.3 E9 ± 3.3 E8
H_2	8.2 E6 ± 1.6 E6	3.1 E8 ± 6.0 E7	9.8 E6 ± 4.0 E5	2.5 E8 ± 1.0 E7
O_2 + Ar	1.1 E7 ± 5.2 E5	4.1 E8 ± 1.9 E7	1.0 E7 ± 1.3 E5	2.6 E8 ± 3.3 E6
N_2	5.8 E8 ± 4.1 E7	2.2 E10 ± 1.5 E9	6.2 E8 ± 4.0 E6	1.6 E10 ± 1.0 E8
CO	3.2 E8 ± 3.9 E7	1.2 E10 ± 1.4 E9	3.6 E8 ± 8.1 E6	9.3 E9 ± 2.1 E8
Moisture	3.4 E7 ± 8.1 E6	1.2 E9 ± 3.0 E8	3.1 E7 ± 5.0 E6	8.0 E8 ± 1.3 E8
CH_4	3.7 E5 ± 3.9 E4	1.4 E7 ± 1.4 E6	3.2 E5 ± 6.5 E4	8.3 E6 ± 1.6 E6
C_2H_6	ND	ND	ND	ND
C_2H_4	ND	ND	<1.1 E3	<2.8 E4
C_3	ND	ND	ND	ND
C_4	ND	ND	ND	ND
C_5	ND	ND	ND	ND
C_6	ND	ND	<1.4 E4	<3.6 E5
Benzene	2.4 E3	9.1 E4	<5.3 E3	<1.3 E5
Toluene	4.7 E4	1.7 E6	1.1 E5 ± 8.6 E4	2.8 E6 ± 2.2 E6
Xylene	1.4 E3	5.3 E4	9.5 E3 ± 4.5 E2	2.4 E5 ± 1.1 E4
H_2S	1.2 E6 ± 5.0 E4	4.4 E7 ± 1.9 E6	1.2 E5 ± 7.9 E3**	3.1 E6 ± 2.0 E5**
COS	2.4 E5 ± 2.1 E4	9.2 E6 ± 7.9 E5	7.9 E5 ± 1.6 E4**	2.0 E7 ± 4.1 E5**
CH_3SH	ND	ND	ND	ND
C_2H_5SH	ND	ND	ND	ND
CS_2	3.1 E3	1.2 E5	<3.1 E3	<8.0 E4
C_4H_4S	ND	ND	ND	ND
SO_2	ND	ND	ND	ND
NH_3	2.9 E4 ± 9.0 E3	1.1 E6 ± 3.4 E5	4.7 E4 ± 2.1 E4	1.2 E6 ± 5.4 E5
HCN	4.3 E4 ± 2.9 E3	1.6 E6 ± 1.1 E5	3.8 E4 ± 1.7 E4	9.8 E5 ± 4.4 E5
Extractable Organics†	1.2 E4	4.5 E5	8.9 E4	2.3 E6
Aerosol Organics#	ND	ND	ND	ND
Particulate	5.7 E5	2.1 E7	6.7 E5	1.7 E7

*Results presented as concentration in dry gas.
**Values are considered to be in error based on flow rates and concentrations in other product gas streams.
†Sum of TCO and GRAV values.
#That portion of aerosol loading extractable with methylene chloride and diethyl ether.
ND - not detected.

TABLE 22. AVERAGE COMPOSITION AND COMPONENT MASS FLOW OF COMBUSTION EMISSIONS FROM BOILER NO. 3 - UMD*

Parameter	Combustion Emissions from Boiler No. 3 Firing ESP Oils		Combustion Emissions from Boiler No. 3 Firing Natural Gas	
	$\mu g/Nm^3 \pm \sigma$	$\mu g/min \pm \sigma$	$\mu g/Nm^3 \pm \sigma$	$\mu g/min \pm \sigma$
CO_2	1.8 E8 ± 9.0 E6	4.5 E10 ± 2.2 E9	1.8 E8	3.2 E10
H_2	ND	ND	ND	ND
O_2 + Ar	1.2 E8 ± 1.8 E7	3.0 E10 ± 4.5 E9	6.4 E7	1.1 E10
N_2	8.9 E8 ± 4.1 E7	2.2 E11 ± 1.0 E10	9.6 E8	1.7 E11
CO	ND	ND	ND	ND
Moisture	5.2 E7 ± 7.4 E5	1.3 E10 ± 1.8 E8	1.1E8 ± 6.3 E6	1.9 E10 ± 1.1 E9
CH_4	ND	ND	ND	ND
C_2H_6	ND	ND	ND	ND
C_2H_4	ND	ND	ND	ND
C_3	ND	ND	ND	ND
C_4	ND	ND	ND	ND
C_5	ND	ND	ND	ND
C_6	ND	ND	ND	ND
Benzene	<8.4 E2	<2.1 E5	NA	NA
Toluene	2.5 E4 ± 2.4 E4	6.2 E6 ± 6.0 E6	NA	NA
Xylene	ND	ND	NA	NA
H_2S	ND	ND	ND	ND
COS	2.5 E3	6.2 E5	ND	ND
CH_3SH	ND	ND	ND	ND
C_2H_5SH	ND	ND	ND	ND
CS_2	ND	ND	ND	ND
C_4H_4S	ND	ND	ND	ND
NH_3	2.3 E3 ± 1.6 E3	5.7 E5 ± 4.0 E5	NA	NA
HCN	5.3 E3 ± 1.5 E3	1.3 E6 ± 3.7 E5	NA	NA
SO_2	3.8 E5 ± 3.0 E4	9.5 E7 ± 7.5 E6	9.6 E3 ± 2.9 E3	1.7 E6 ± 5.2 E5
NO_x (as NO_2)	7.9 E5 ± 4.5 E4	1.9 E8 ± 1.1 E7	2.1 E5 ± 4.5 E3	3.7 E7 ± 8.1 E5
Extractable Organics†	2.7 E3	6.7 E5	NA	NA
Aerosol Organics#	1.0 E3	2.5 E5	NA	NA
Particulate	4.8 E4	1.2 E7	NA	NA

*Results presented as concentration in dry gas.
†Sum of TCO and GRAV values.
#That portion of aerosol loading extractable with methylene chloride and diethyl ether.
ND - not detected.
NA - not analyzed.

The mass flow rate for toluene in the combustion emissions was lower (5.9E6 μg/min) than in the combined product gas (2.4E7 μg/min), while xylene was not detected in the combustion emissions. The mass flow rate of extractable organics was reduced from 2.3E8 μg/min in the combined product gas to 7.6E3 μg/min in the combustion emissions from the product gas boilers. Mass flow rates for ammonia and cyanide (4.7E7 μg/min and 1.3E7 μg/min, respectively) in the combined product gas were reduced by approximately two orders of magnitude in the combustion emissions.

The combined product gas stream and the emissions from the product gas boiler were sampled on the same day and analyzed to determine a material balance for the product gas boiler. The combined mass flow of organic nitrogen, ammonia, and cyanide in the combined product gas is equivalent to 0.78 g/s nitrogen. Nitrogen enters the gasifier with the coal at a rate of 3.9 g/s (no contribution from nitrogen in the blast air is included). The gasification process effectively removes 80 percent of the fuel nitrogen and converts approximately 20 percent to gaseous components that may contribute to emissions of nitrogen oxides (2.3 g/s as NO_2 or 0.72 g/s as N) from the boiler. The measured emission rate of NO_x from the product gas boilers represents a 92 percent conversion of nitrogen compounds in the fuel gas to NO_x in the combustion emissions and is equivalent to 310 ng/J, or 0.72 lb/E^6 Btu. Somewhat more S (1.5 g/s) as SO_2 was found in the combustion emission stream from the product gas boilers than was accounted for in the combined product gas feed (1.1 g/s). The data indicate that greater than 100 percent conversion of fuel gas sulfur to SO_2 occurs during the combustion process. This is the equivalent of 440 ng/J or 0.99 lb/E^6 Btu (see Table 23). This discrepancy between in and out is not inconsistent within the limitations imposed by the sampling and analytical techniques which were used.

There was no change in the gas composition for the top product gases as a result of the gas clean-up, except for aerosol organics and particulates. The effect of the ESP on aerosols in the top product gas is discussed in Section 5.6. Samples of bottom gas collected downstream of the cyclone showed an apparent reduction of H_2S flow rate by an order of magnitude and

an apparent tripling of the COS flow rate. Those values are reported in Table 21. Based on relative flow rates of H_2S and COS in the raw bottom gas, raw and cleaned top gas, and combined product gas, it is concluded that the values reported for H_2S and COS flow rates are in error. This error may have resulted from sample degradation prior to analysis, perhaps because of inadequate drying of the gaseous sample during collection in the sample bomb. No other changes in gas composition were observed in the bottom gas stream (2).

The majority of the gas-phase organics exits the gasification process in the top gas. The mass flow of C_1-C_6 hydrocarbons (9.5E8 μg/min) in the treated top gas is about two orders of magnitude higher than the mass flow rate for C_1-C_6 hydrocarbons in the treated bottom gas (8.7E6 μg/min). The mass flow rates of benzene, toluene, and xylene were about an order of magnitude higher in the treated top gas (6.9E7 μg/min) than in the treated bottom gas (6.1E6 μg/min). The gaseous sulfur species in the combined product gas are comprised of H_2S (88%), COS (9%) and CH_3SH (3%) with trace amounts of C_2H_5SH, CS_2, and C_4H_4S. The mass flow rates of organic sulfur species associated with a hydrocarbon moiety were higher in the treated top gas than in the treated bottom gas, as expected. The treated top gas was found to contain methyl mercaptan (2.5E5 μg/min), ethyl mercaptan (2.5E5 μg/min), and thiophene (1.1E5 μg/min), which were not detected in the treated bottom gas. Mass flow rates for extractable organics in the treated top gas (2.4E8 μg/min) were two orders of magnitude higher than in the treated bottom gas (2.3E6 μg/min). The combined concentrations of NH_3 and HCN in the treated top gas (~1.8E6 μg/Nm^3) is over an order of magnitude higher than their combined concentrations in the treated bottom gas (~8.5E4 μg/Nm^3) (2).

The amount of HCN measured in the combined gases appears high in light of the low levels of CO and NH_3. This may be the result of contamination or the presence of an interferent. However, since no blank runs were made this cannot be confirmed.

The oxygen levels cited in Tables 20 through 22 and in the appendix tables appear high because they represent combined O_2 and Ar. The analytical technology did not provide for separation of O_2 and Ar. In any case, O_2 originating from air and from the coal cannot be distinguished.

The combustion emissions from Boiler No. 3 firing ESP oil and from Boiler No. 3 during the combustion of natural gas were collected to identify any differences that may be observed when firing natural gas and liquid synfuels in the same boiler. These results are presented in Table 22. Individual analytical results and the time of collection of samples are presented in Appendices A and B.

Table 23 presents calculated emission rates for SO_2, NO_x (as NO_2), and particulates in the discharge streams (boiler flue gases). Emission rates were calculated for emissions from the combustion of product gas, ESP oil, and natural gas.

TABLE 23. EMISSIONS OF SO_2, NO_x, and PARTICULATE: CALCULATED VALUES FOR UMD BOILERS

	Combustion Emissions		
Fuel to Boiler	SO_2 lb/E6 Btu (ng/J)	NO_x (as NO_2) lb/E6 Btu (ng/J)	Particulate lb/E6 Btu (ng/J)
Product Gas*	1.29 (560)	0.94 (400)	0.072 (31)
Product Gas†	0.99 (440)	0.72 (310)	0.055 (24)
ESP Oil#	0.34 (150)	0.70 (300)	0.042 (18)
Natural Gas**	0.01 (4)	0.02 (90)	NA††

*Based on calculated heat content of product gas.
†Based on average high heating value of coal from proximate/ultimate analyses (moisture free).
#Based on high heating value of ESP oil to Boiler No. 3 from proximate/ultimate analyses.
**Based on high heating value of natural gas from a reference manual.
††NA - not analyzed.

At maximum capacity, the UMD gasifier has a feed rate of approximately 72E6 Btu/hr and produces enough low-Btu gas to fire a 55E6 Btu/hr steam boiler (44,000 lb/hr steam). The current Federal New Source Performance Standards (NSPS) for fossil-fuel-fired steam generators apply to boilers with a heat input of 250E6 Btu/hr or greater; therefore, the NSPS would not apply to a facility of this size. The U.S. EPA is expected to present a revised NSPS which may have a lower applicability threshold and more stringent emission standards.

Emissions from the UMD boilers firing gasifier product gas can, however, be compared to the emission limitations in the current NSPS for coal combustion. Table 24 presents this comparison. The SO_2 and particulate emissions meet the NSPS limitations if the emission rate is calculated according to the gas firing rate to the boiler. The NO_x emissions are slightly above the NSPS level. If the emission rates are calculated according to the heating value of the coal used to produce the gas, the SO_2 and NO_x emissions exceed the NSPS limit, while particulate emissions remain below the standard.

TABLE 24. COMPARISON OF NSPS LIMITATIONS FOR FOSSIL-FUEL FIRED WITH UMD BOILER EMISSIONS

Pollutant	NSPS*	Product Gas†	Product Gas#
SO_2 (lb/E6Btu)	1.2	1.29	0.99
NO_x (lb/E6Btu)	0.70	0.94	0.72
Particulate (lb/E6Btu)	0.10	0.072	0.055

*40 CFR60, SUBPART D, emission limitation for solid fossil fuel.
†Based on calculated heat content of product gas.
#Based on average high heating value of coal from proximate/ultimate analysis (moisture free).

5.6 Efficiency of Gas Clean-up Devices

The efficiencies of control devices for removal of aerosolized oils and particulate from the product gas were evaluated by obtaining gravimetric measurements of aerosol and particulate loadings on both sides of the clean-up devices. The results of the analyses are summarized in Tables 20 and 21.

The collection efficiency of the top product gas ESP was calculated to be 98 percent for aerosolized oils and 74 percent for particulates based on loadings. Correcting for differences in measured gas volumes through the clean-up device, the collection efficiency was 98 percent for aerosolized oils and 72 percent for particulates based on mass flow. The efficiency of the cyclone was not evaluated because of difficulties in determining a consistent gas flow at the sampling points. The sampling valve was located approximately 30 cm upstream of a butterfly control valve which may disrupt the flow pattern of the bottom gas as it leaves the cyclone. The efficiency determined for the ESP may also be questionable due to the possible flow disruptions caused by the injection of treated bottom gas into raw top gas. This disruption could not be defined because only one sampling port was available and only a single traverse could be performed at the sampling location for the raw top gas. In addition, the configuration of the pipe transporting the treated top gas might result in the collection of a non-representative sample.

5.7 Water Quality

The ash pan water was analyzed for water quality parameters in addition to trace elements and extractable organics. The presence and concentration of components in the ash pan water are probably due primarily to the dissolution of components from the gasifier ash into the ash pan water. No analysis was performed on the service water. The flow rate of the ash pan water is quite low because the waters are not discharged directly. Ash pan water losses result from carry over with the discharged gasifier ash and, to a small extent, from evaporation.

Table B-38 in Appendix B presents the analytical results for water quality parameters in the ash pan water. Elemental concentrations in the ash pan water are presented in Table B-33. The ash pan water composition was compared to National Interim Primary Drinking Water Standards (NIPDWS) which are federally enforceable standards for drinking water. The ash pan water was also compared to National Secondary Drinking Water Regulations (NSDWR) guidelines, which are intended to serve as non-enforceable guidelines relating to aesthetic qualities and public acceptance of drinking water. The comparison is presented in Table 25. Note that this comparison is between a process wastewater and drinking water standards. The impact of parameters exceeding the drinking water standards would be lessened upon dilution of the ash pan water in a receiving water stream as well as by other factors specific to a given site. Concentrations of barium and mercury in the ash pan water exceed NIPDWS, and the concentration of chromium equals NIPDWS. The pH of the ash pan water is not within the guidelines of NSDWR, and the concentration of total dissolved solids exceeds NSDWR. The concentration of mercury in the ash pan water may not be typical of process conditions. During initial start-up of the gasifier, a large quantity of mercury serving as a seal was spilled into the ash pan. The mercury was cleaned up, and the mercury seal was replaced with a mechanical seal, but traces of mercury probably still contaminate the ash pan.

5.8 RCRA Leaching

The ultimate environmental fate of trace elements found in gasifier ash and cyclone dust depends upon the method of disposal and leaching of materials from the solid wastes by groundwater or run-off waters. In response to the Resource Conservation and Recovery Act (RCRA), EPA has promulgated regulations which define solid and hazardous wastes and has specified procedures for handling and disposal of them. The regulations include five criteria which define the characteristics of a hazardous waste. The category most pertinent to solid waste from gasification processes is Extraction Procedures (EP) toxicity.

TABLE 25. COMPARISON OF ASH PAN WATER TO DRINKING WATER STANDARDS†

Parameter	NIPDWS*	NDSWR**	Ash Pan Water	
			Concentration	Range
As	50		<2	
Ba	1,000		1,500	
Cd	10		<1	
Cl^-		250,000	200,000***	190,000 - 210,000
Cr	50		50	
Cu		1,000	60	
F^-	1,800		560***	480 - 640
Fe		300	<8	
Pb	50		10	
Mn		50	8	
Hg****	2		4.2	
Se	10		<3	
Ag	50		<1	
Zn		5,000	9	
NO_3^-(as N)		10,000	2,700***	1,100 - 4,400
$SO_4^=$		250,000	58,000***	56,000 - 61,000
pH		6.5-8.5	12.51***	12.48 - 12.54
TDS		500,000	1,800,000***	1,700,000 - 2,000,000

†Concentrations in μg/L.
*National Interim Primary Drinking Water Standards.
**National Secondary Drinking Water Regulations.
***Values given are averages of two analyses.
****Concentrations of Hg may not be typical because of spill contamination.

The test for EP toxicity is intended to simulate the release of leachate from landfills under conditions of improper management. The extraction procedure is defined, and maximum concentrations of contaminants that can be permitted in the resulting leachate are specified. Fourteen contaminants (eight trace elements, four pesticides, and two herbicides) are specified. The results of RCRA EP toxicity testing are presented in Table 26. Analyses were performed only for the eight trace elements, since little rationale exists for the presence of the listed pesticides and/or herbicides in the coal or for their production by the process. A previous study (3) has verified this concept.

TABLE 26. RESULTS OF RCRA EP TOXICITY TESTING IN SOLID WASTES FROM FOSTER WHEELER/STOIC TWO-STAGE GASIFIER - UMD*

Element	Gasifier Ash	Cyclone Dust	Maximum Permissible Concentration†
Arsenic	<3	120	5,000
Barium	650	6,900	100,000
Cadmium	100	<100	1,000
Chromium	<200	<200	5,000
Lead	<200	<200	5,000
Mercury#	<0.2	2.9	200
Selenium	<4	<4	1,000
Silver	<60	<60	5,000

*Concentrations in μg/L.
†RCRA Extraction Procedure toxicity.
#Concentrations of Hg may not be typical because of spill contamination.

According to the results of EP toxicity testing, the gasifier ash and cyclone dust can be considered as non-hazardous solid wastes. None of the eight trace elements were found in the extracts at levels greater than ten percent of the maximum allowable concentration, as specified in RCRA.

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APPENDIX A
SAMPLING DATA

A.1.0 SAMPLING DATA

The sampling data for the UMD gasification facility are presented in this appendix. Table A-1 gives the physical parameters for the gaseous streams. Tables A-2 and A-3 give sample volumes, stream concentration, and collection efficiencies for gaseous ammonia and cyanide samples, respectively. Tables A-4 and A-5 give sample volumes for gaseous trace metals and organic samples, respectively. Tables A-6 and A-7 give sample volumes and stream concentrations for NO_x and SO_x, respectively. The sampling log is presented in Table A-8.

TABLE A-1. PHYSICAL PARAMETERS DATA FOR THE UMD GASEOUS PROCESS AND EMISSION STREAMS

Combined Product Gas:

Flow Rate:	62.9 Nm^3/min (760 mm Hg and 25°C, dry) (2150 scfm, 934 g/s)
Velocity:	11.2 m/s (stream conditions) (23.7 fps)
Temperature:	242°C (468°F)
Pressure:	805 mm/Hg (31.7 in Hg)
% Moisture:	9.6
Molecular Weight:	23.2
Sampling Date:	February 24, 1981 (NH_3, HCN only); February 25, 1981.

Cleaned Bottom Gas:

Flow Rate:	26.3 Nm^3/min (760 mm Hg, 25°C, dry) (900 scfm, 378 g/s)
Velocity:	2.70 m/s (stream conditions) (8.87 fps)
Temperature:	418°C (785°F)
Pressure:	774 mm Hg (30.48 in Hg)
% Moisture:	4.4
Molecular Weight:	24.8
Sampling Date:	March 5, 1981

Raw Bottom Gas:

Flow Rate:	37.7 Nm^3/min (760 mm Hg, 25°C, dry) (1290 scfm, 673 g/s)
Velocity:	3.04 m/s (stream conditions) (9.97 fps)
Temperature:	514°C (958°F)
Pressure:	774 mm Hg (30.48 in. Hg.)
% Moisture:	4.5
Molecular Weight:	25.9
Sampling Date:	March 5, 1982

Cleaned Top Gas:

Flow Rate:	33.6 Nm^3/min (760 mm Hg, 26°C, dry) (1150 scfm, 559 g/s)
Velocity:	6.19 m/s (stream conditions) (20.7 fps)
Temperature:	58.9°C (192°F)
Pressure:	762 mm Hg (30.01 in Hg)
% Moisture:	19.2
Molecular Weight:	23.2
Sampling Date:	February 27, 1981

(Continued)

TABLE A-1. (Continued)

Raw Top Gas:

Flow Rate:	32.8 Nm^3/min (760 mm Hg, 25°C, dry) (1120 scfm, 534 g/s)
Velocity:	9.14 m/s (stream conditions) (30.0 fps)
Temperature:	90°C (194°F)
Pressure:	762 mm Hg (30.01 in Hg)
% Moisture:	19.3
Molecular Weight:	22.8
Sampling Date:	February 27, 1981

Boiler No. 3 Firing ESP Oil:

Flow Rate:	251 Nm^3/min (760 mm Hg, 25°C, dry) (8530 scfm, 5150 g/s)
Velocity:	8.47 m/s (stream conditions) (27.8 fps)
Temperature:	331°C (628°F)
Pressure:	719 mm Hg (28.3 in Hg)
% Moisture:	7.0
Molecular Weight:	29.2
Sampling Date:	March 3, 1981

Boiler No. 3 Firing Natural Gas:

Flow Rate:	181 Nm^3/min (760 mm Hg, 25°C, dry) (6190 scfm, 3680 g/s)
Velocity:	6.55 m/s (stream conditions) (21.5 fps)
Temperature:	286°C (547°F)
Pressure:	720 mm Hg (28.36 in Hg)
% Moisture:	15
Molecular Weight:	28.0
Sampling Date:	March 4, 1981

Product Gas Boiler:

Flow Rate:	274 Nm^3/min (760 mm Hg, 25°C, dry) (9370 scfm, 5570 g/s)
Velocity:	4.69 m/s (stream conditions) (15.4 fps)
Temperature:	241°C (465°F)
Pressure:	759 mm Hg (29.90 in Hg)
% Moisture:	9.2
Molecular Weight:	28.2
Sampling Date:	February 25, 1981

TABLE A-2. UMD GASIFICATION FACILITY: SAMPLING DATA FOR GASEOUS AMMONIA SAMPLES

Description	Sample Volume SCF 60°F, 1 atm.	Sample Volume Nm^3 25°C 1 atm.	1st Imp mg NH_3	2nd Imp mg NH_3	Total NH_3	ppm NH_3	Collection Efficiency (%)
Combined Gas Run #1 2/24 2024-2036 hrs	3.794	0.1110	98.6	2.05	100.6	1310	98.0
Combined Gas Run #2 2/25 0513-0529 hrs	4.403	0.1288	100.5	2.13	102.6	1150	97.9
Combined Gas Run #3 2/25 0937-0952 hrs	3.480	0.1018	86.6	2.20	88.8	1260	97.5
Product Gas Boiler Run #1 2/25 0222-0312 hrs	22.547	0.6594	<0.15	<0.13	<0.28	<0.6	--
Product Gas Boiler Run #2 2/25 0820-0910 hrs	21.127	0.6179	<0.15	<0.12	<0.27	<0.6	--
Cleaned Top Gas Run #1 2/27 1055-1111 hrs	3.610	0.1056	189.0	0.56	189.5	2590	99.7
Cleaned Top Gas Run #2 2/27 1655-1737 hrs	6.554	0.1917	319.3	1.38	320.7	2410	99.6
Cleaned Top Gas Run #3 2/27 2045-2057 hrs	3.069	0.0898	164.0	2.18	166.2	2670	98.7
Raw Top Gas Run #1 2/27 1047-1057 hrs	3.430	0.1003	175.8	1.32	177.1	2540	99.3
Raw Top Gas Run #2 2/27 1405-1415 hrs	2.395	0.0700	125.9	0.56	126.5	2600	99.6
Raw Top Gas Run #3 2/27 1706-1726 hrs	5.008	0.1465	217.2	1.23	218.4	2150	99.4
ESP Oil Boiler Run #1 3/3	19.024	0.5564	0.62	<0.12	<0.74	1.6	>83.8
ESP Oil Boiler Run #2 3/3	18.957	0.5544	0.18	0.12	<0.30	0.5	>60.0

(Continued)

TABLE A-2. (Continued)

Description	Sample Volume SCF 60°F, 1 atm.	Sample Volume Nm^3 25°C 1 atm.	1st Imp mg NH_3	2nd Imp mg NH_3	Total NH_3	ppm NH_3	Collection Efficiency (%)
Cleaned Bottom Gas Run #1 3/5 1437-1452 hrs	5.728	0.1675	9.51	0.92	10.4	89.7	91.2
Cleaned Bottom Gas Run #2 3/5 1923-1937 hrs	3.814	0.1115	3.23	0.38	3.61	46.6	89.5
Cleaned Bottom Gas Run #3 3/6 0103-0113 hrs	4.002	0.1170	97.8	0.33	98.1	1210	99.7
Raw Bottom Gas Run #1 3/5 1508-1532 hrs	3.525	0.1031	3.69	<0.12	<3.81	51.5	>96.9
Raw Bottom Gas Run #2 3/5 2111-2128 hrs	3.781	0.1106	2.29	0.22	2.51	32.7	91.2
Raw Bottom Gas Run #3 3/6 0114-0129 hrs	3.617	0.1058	47.3	<0.06	<47.4	644	>99.9

TABLE A-3. UMD GASIFICATION FACILITY: SAMPLING DATA FOR GASEOUS CYANIDE SAMPLES

Description	Sample Volume SCF 60°F, 1 atm.	Sample Volume Nm^3 25°C 1 atm.	1st Imp mg NH_3	2nd Imp mg NH_3	Total NH_3	ppm NH_3	Collection Efficiency (%)
Combined Gas Run #1 2/24 2041-2055 hrs	4.165	0.1218	24.2	0.40	24.6	183	98.4
Combined Gas Run #2 2/25 0537-0551 hrs	4.353	0.1273	33.5	0.25	33.8	240	99.3
Combined Gas Run #3 2/25 0955-1010 hrs	3.170	0.0927	22.4	0.16	22.6	221	99.3
Product Gas Boiler Run #1 2/25 0323-0415 hrs	24.192	0.7075	1.23	<0.40	<1.63	1.6	>75.0
Product Gas Boiler Run #2 2/25 0618-0658 hrs	18.389	0.5378	0.89	0.005	0.89	1.5	99.4
Cleaned Top Gas Run #1 2/27 1015-1050 hrs	4.104	0.1200	33.4	0.39	33.8	255	98.8
Cleaned Top Gas Run #2 2/27 1617-1652 hrs	3.958	0.1158	32.3	0.14	32.4	254	99.6
Cleaned Top Gas Run #3 2/27 2028-2040 hrs	3.373	0.0986	19.2	0.36	19.6	180	98.2
Raw Top Gas Run #1 2/27 1033-1043 hrs	3.938	0.1152	34.9	0.38	35.3	278	98.9
Raw Top Gas Run #2 2/27 1348-1358 hrs	2.720	0.0795	20.7	0.28	21.0	239	98.7
Raw Top Gas Run #3 2/27 1643-1703 hrs	3.784	0.1107	26.8	0.31	27.1	222	98.9
ESP Oil Boiler Run #1 3/3 0945-1047	19.107	0.5588	0.93	1.42	2.35	3.8	39.6
ESP Oil Boiler Run #2 3/3 1626-1736	17.968	0.5255	2.88	0.43	3.31	5.7	87.0

(Continued)

TABLE A-3. (Continued)

Description	Sample Volume SCF 60°F, 1 atm.	Sample Volume Nm^3 25°C 1 atm.	1st Imp mg NH_3	2nd Imp mg NH_3	Total NH_3	ppm NH_3	Collection Efficiency (%)
Cleaned Bottom Gas Run #1 3/5 1417-1434 hrs	4.550	0.1331	6.67	0.04	6.71	45.7	99.4
Cleaned Bottom Gas Run #2 3/5 1905-1919 hrs	3.976	0.1163	4.98	<0.37	<5.35	38.8	>93.1
Cleaned Bottom Gas Run #3 3/6 0117-0127 hrs	4.091	0.1196	2.25	<0.38	<2.63	17.0	>85.6
Raw Bottom Gas Run #1 3/5 1440-1504 hrs	3.726	0.1090	5.07	0.03	5.10	42.4	98.2
Raw Bottom Gas Run #2 3/5 2052-2106 hrs	4.022	0.1176	4.90	0.05	4.95	38.2	98.9
Raw Bottom Gas Run #3 3/6 0057-0111 hrs	3.704	0.1083	4.46	0.02	4.48	37.5	99.6

TABLE A-4. UMD GASIFICATION FACILITY: SAMPLING DATA FOR GASEOUS TRACE METAL SAMPLES

Stream	Sample Volume	
	SCF 600°F 1 atm.	Nm^3 25°C 1 atm.
Combined Product Gas 2/25 0125-0415 hrs	50.9	1.49
Product Gas Boiler 2/25 0057-0701 hrs	548.0	16.0
Cleaned Top Gas 2/27 1116-1615 hrs	42.2	1.23
Raw Top Gas 2/27 1102-0332 hrs	41.6	1.22
ESP Oil Boiler 2/27 1052-1730 hrs	573.0	16.8
Cleaned Bottom Gas 3/5 1456-1856 hrs	54.3	1.59
Raw Bottom Gas 3/5 1534-2040 hrs	47.7	1.39

TABLE A-5. UMD GASIFICATION FACILITY: SAMPLING DATA FOR GASEOUS ORGANIC SAMPLES

Stream	Sample Volume	
	SCF 600°F 1 atm.	Nm^3 25°C 1 atm.
Combined Product Gas 2/25 0647-0927 hrs	43.6	1.28
Product Gas Boiler 2/25 0057-0701 hrs	548.0	16.0
Cleaned Top Gas 2/27 1802-2022 hrs	52.9	1.55
Raw Top Gas 2/27 1435-1635 hrs	27.4	0.80
ESP Oil Boiler 2/27 1052-1730 hrs	573.0	16.8
Cleaned Bottom Gas 3/5 2004-0056 hrs	100.0	2.93
Raw Bottom Gas 3/5 2137-0046 hrs	46.9	1.37

TABLE A-6. UMD GASIFICATION FACILITY: SAMPLING DATA FOR GASEOUS NO_x SAMPLES

Description	Sample Volume SCF 60°F, 1 atm.	Sample Volume Nm^3 25°C, 1 atm.	μg NO_2	ppm NO_x
Product Gas Boiler 2/26 Bomb 21 0525 hrs	0.0497	0.001454	932	341
Product Gas Boiler 2/26 Bomb 34 0525 hrs	0.0500	0.001462	750	273
Product Gas Boiler 2/27 Bomb 28 1005 hrs	0.0501	0.001465	571	207
Boiler #3 ESP Oil 3/3 Bomb 28 1522 hrs	0.0509	0.001489	1,120	400
Boiler #3 ESP Oil 3/3 Bomb 34 1522 hrs	0.0502	0.001468	1,240	449
Boiler #3 ESP Oil 3/3 Bomb 27 1910 hrs	0.0478	0.001398	1,115	424
Boiler #3 ESP Oil 3/3 Bomb 21 1910 hrs	0.0477	0.001395	1,045	399
Boiler #3 Natural Gas 3/4 Bomb 24 1022 hrs	0.0466	0.001363	277	108
Boiler #3 Natural Gas 3/4 Bomb 26 1022 hrs	0.0442	0.001293	272	112
Boiler #3 Natural Gas 3/4 Bomb 20 1127 hrs	0.0432	0.001263	264	111
Boiler #3 Natural Gas 3/4 Bomb 22 1127 hrs	0.0443	0.001296	260	107

TABLE A-7. UMD GASIFICATION FACILITY: SAMPLING DATA FOR GASEOUS SO_x SAMPLES

Description	Sample Volume SCF 60°F 1 atm.	Sample Volume Nm^3 25°C, 1 atm.	1st Imp Mg SO_2	2nd Imp Mg SO_2	Total Mg SO_2	ppm SO_2	Collection Efficiency (%)
Product Gas Boiler Run #1 2/25 0422-0500 hrs	16.159	0.4726	336.5	8.07	344.6	279	97.6
Product Gas Boiler Run #2 2/25 0723-0800 hrs & 0915-0945 hrs	26.181	0.7657	510.1	10.2	520.3	260	98.0
Boiler #3 ESP Oil Run #1 3/3 1209-1251 hrs	15.253	0.4461	183.1	1.61	184.7	158	99.1
Boiler #3 ESP Oil Run #2 3/3 1358-1430 hrs	11.711	0.3425	139.7	1.06	140.8	157	99.2
Boiler #3 ESP Oil Run #3 3/3 1601-1623 hrs	9.314	0.2724	95.5	1.00	96.5	135	98.9
Boiler #3 ESP Oil Run #4 3/3 1739-1810 hrs	5.683	0.1662	59.6	1.31	60.9	140	97.8
Boiler #3 Natural Gas Run #1 3/4 1115-1145 hrs	12.945	0.3786	4.04	0.68	4.72	4.8	85.6
Boiler #3 Natural Gas Run #2 3/4 1148-1218 hrs	11.637	0.3403	2.90	0.35	3.25	3.7	89.2
Boiler #3 Natural Gas Run #3 3/4 1233-1303 hrs	10.005	0.2926	1.61	0.36	1.97	2.6	81.7

TABLE A-8. SAMPLE LOGBOOK

Sample Number	Date	Sample Type	Sample Description or Parameter
UMD-001	02-24-81	Wastewater	Ash Pan Water 1100
UMD-002	02-24-81	Gas	Combined Gas - CN Run #1 Imp. #1
UMD-003	02-24-81	Gas	Combined Gas - CN Run #1 Imp. #2
UMD-004	02-24-81	Gas	Combined Gas NH_3 Run #1 Imp. #1
UMD-005	02-24-81	Gas	Combined Gas NH_3 Run #1 Imp. #2
UMD-006	02-25-81	Gas	Main Stack CN Run #1 Imp. #1
UMD-007	02-25-81	Gas	Main Stack CN Run #1 Imp. #2
UMD-008	02-25-81	Gas	Main Stack NH_3 Run #1 Imp #1
UMD-009	02-25-81	Gas	Main Stack NH_3 Run #1 Imp. #2
UMD-010	02-25-81	Gas	Combined Gas CN Run #2 Imp. #1
UMD-011	02-25-81	Gas	Combined Gas CN Run #2 Imp. #2
UMD-012	02-25-81	Gas	Combined Gas NH_3 Run #2 Imp. #1
UMD-013	02-25-81	Gas	Combined Gas NH_3 Run #2 Imp. #2
UMD-014	02-25-81	Gas	SO_2 Run #1 Imp. #1 Main Stack
UMD-015	02-25-81	Gas	Main Stack SO_2 Run #1 Imp. #2
UMD-016	02-25-81	Gas	Main Stack CN Run #2 Imp. #1
UMD-017	02-25-81	Gas	Main Stack CN Run #2 Imp. #2
UMD-018	02-25-81	Wastewater	Ash Pan Composite--See also 056,304 (02-24-81) 1600, 2020 hrs (02-25-81) 0200, 0620 hrs
UMD-019	02-25-81	Filter	Main Stack SASS #1
UMD-020	02-25-81	Gas	Combined Gas CN Run #3 Imp. #1
UMD-021	02-25-81	Gas	Combined Gas CN Run #3 Imp. #2
UMD-022	02-25-81	Gas	Main Stack NH_3 Run #2 Imp. #1
UMD-023	02-25-81	Gas	Main Stack NH_3 Run #2 Imp. #1
UMD-024	02-25-81	Gas	Combined Gas Run #3 NH_3 Imp. #1
UMD-025	02-25-81	Gas	Combined Gas NH_3 Run #3 Imp. #2
UMD-026	02-25-81	Gas	Main Stack SO_2 Run #2 Imp. #1
UMD-027	02-25-81	Gas	Main Stack SO_2 Run #2 Imp. #2
UMD-028	02-24-81	Solid	Coal - 1030 hrs
UMD-029	02-24-81	Solid	Coal - 1630 hrs
UMD-030	02-24-81	Solid	Coal - 1945 hrs
UMD-031	02-25-81	Solid	Coal - 0145 hrs
UMD-032	02-25-81	Solid	Coal - 1615 hrs
UMD-033	--	--	No sample
UMD-034	02-27-81	Gas	Cleaned Top Gas Cn Run #1 Imp. #1
UMD-035	02-27-81	Gas	Cleaned Top Gas CN Run #1 Imp. #2
UMD-036	02-27-81	Gas	Raw Top Gas CN Run #1 Imp. #1
UMD-037	02-27-81	Gas	Raw Top Gas CN Run #1 Imp. #2
UMD-038	02-27-81	Gas	Cleaned Top Gas NH_3 Run #1 Imp. #1
UMD-039	02-27-81	Gas	Cleaned Top Gas NH_3 Run #1 Imp. #2

(Continued)

TABLE A-8. (Continued)

Sample Number	Date	Sample Type	Sample Description or Parameter
UMD-040	02-27-81	Gas	Raw Top Gas NH_3 Run #1 Imp. #1
UMD-041	02-27-81	Gas	Raw Top Gas NH_3 Run #1 Imp. #2
UMD-042	02-27-81	Gas	Raw Top Trace Metals Imp. #1
UMD-043	02-27-81	Gas	Raw Top Trace Metals Imp. #2
UMD-044	02-27-81	Gas	Raw Top Gas CN Run #2 Imp. #1
UMD-045	02-27-81	Gas	Raw Top Gas CN Run #2 Imp. #2
UMD-046	02-27-81	Gas	Raw Top Gas NH_3 Run #2 Imp. #1
UMD-047	02-27-81	Gas	Raw Top Gas NH_3 Run #2 Imp. #2
UMD-048	02-27-81	Gas	Raw Top Trace Metals Imp. Rinse Methylene Chloride
UMD-049	02-25-81	Gas	Combined Gas Trace Metals Imp. #1
UMD-050	02-27-81	Gas	Combined Gas Trace Metals Imp. #2
UMD-051	02-25-81	Gas	Combined Gas Metals Impingers $MeCl_2$ Rinse
UMD-052	02-27-81	Gas	Cleaned Top Gas CN Run #2 Imp. #1
UMD-053	02-27-81	Gas	Cleaned Top Gas CN Run #2 Imp. #2
UMD-054	02-27-81	Gas	Cleaned Top Gas Trace Metals Imp. #1
UMD-055	02-27-81	Gas	Cleaned Top Gas Trace Metals Imp. #2
UMD-056	02-27-81	Water	Ash Pan Water Composite Grabs Taken at 11:15, 14:20, 17:35 hours.
UMD-057	02-27-81	Gas	Raw Top Gas CN Run #3 Imp. #1
UMD-058	02-27-81	Gas	Raw Top Gas CN Run #3 Imp. #2
UMD-059	02-27-81	Gas	Cleaned Top Gas CN Run #3 Imp. #1
UMD-060	02-27-81	Gas	Cleaned Top Gas CN Run #3 Imp. #2
UMD-061	02-27-81	Gas	Raw Top Gas NH_3 Run #3 Imp. #1
UMD-062	02-27-81	Gas	Raw Top Gas NH_3 Run #3 Imp. #2
UMD-063	02-27-81	Gas	Cleaned Top Gas NH_3 Run #3 Imp. #1
UMD-064	02-27-81	Gas	Cleaned Top Gas NH_3 Run #3 Imp. #2
UMD-065	02-27-81	Gas	Cleaned Top Gas NH_3 Run #2 Imp. #1
UMD-066	02-27-81	Gas	Cleaned Top Gas NH_3 Run #2 Imp. #2
UMD-067	02-25-81	Gas	SASS #1 Condensate, Main Stack
UMD-068	02-25-81	Gas	SASS #1, 1st Impinger, Main Stack
UMD-069	02-25-81	Gas	SASS #1, 2nd & 3rd Impingers, Main Stack
UMD-070	02-25-81	Gas	SASS #1, Resin & Rinse #1, Main Stack
UMD-071	02-25-81	Gas	Organics, Resin & Rinse, Combined Gas
UMD-072	02-24-81 02-25-81	Gas	Trace Metals, Filter 2.2830 gm, Combined Gas
UMD-073	02-24-81 02-25-81	Gas	Organics, NH_3, CN, Filter 2.1039, Combined Gas

(Continued)

TABLE A-8. (Continued)

Sample Number	Date	Sample Type	Sample Description or Parameter
UMD-074	02-24-81 02-25-81	Gas	Particle Load, Filter 2.6364, Main Stack
UMD-075	02-25-81	Gas	SASS #1, Condenser Rinse Main Stack
UMD-076	02-25-81	Gas	SASS #1, Probe Cyclone Filter Rinse, Main Stack
UMD-077	02-25-81	Gas	Organics, Condenser Rinse, Combined Gas
UMD-078	02-25-81	Gas	SASS #1, Resin & Rinse #2, Main Stack
UMD-079	02-25-81	Tar	ESP Tar Grab, 11:15 hrs
UMD-080	02-25-81	Solid	Gasifier Ash, 11:05 hrs
UMD-081	03-03-81	Gas	Stub Stack CN Run #1 Imp. #1
UMD-082	03-03-81	Gas	Stub Stack CN Run #1 Imp. #2
UMD-083	03-03-81	Gas	Stub Stack SO_2 Run #1 Imp. #1
UMD-084	03-03-81	Gas	Stub Stack SO_2 Run #1 Imp. #2
UMD-085	03-03-81	Gas	Stub Stack NH_3 Run #1 Imp. #1
UMD-086	03-03-81	Gas	Stub Stack NH_3 Run #1 Imp. #2
UMD-087	03-03-81	Gas	Stub Stack SO_2 Run #2 Imp. #1
UMD-088	03-03-81	Gas	Stub Stack SO_2 Run #2 Imp. #2
UMD-089	03-03-81	Gas	Stub Stack SO_2 Run #2 Imp. #1
UMD-090	03-03-81	Gas	Stub Stack SO_2 Run #2 Imp. #2
UMD-091	03-03-81	Gas	Stub Stack NH_3 Run #2 Imp. #1
UMD-092	03-03-81	Gas	Stub Stack NH_3 Run #2 Imp. #2
UMD-093	03-03-81	Gas	Stub Stack CN Run #2 Imp. #1
UMD-094	03-03-81	Gas	Stub Stack CN Run #2 Imp. #2
UMD-095	03-03-81	Gas	Stub Stack SASS Run Imp. #1 and Wash
UMD-096	03-03-81	Gas	Stub Stack SASS Run Imp. #2
UMD-097	03-03-81	Gas	Stub Stack SO_2 Run #4 Imp. #1
UMD-098	03-03-81	Gas	Stub Stack SO_3 Run #4 Imp. #2
UMD-099	02-24-81	Tar	ESP Tar 1100 hrs
UMD-100	02-24-81	Tar	ESP Tar 1640 hrs
UMD-101	02-24-81	Tar	ESP Tar 2005 hrs
UMD-102	02-24-81	Tar	ESP Tar 0155 hrs
UMD-103	02-28-81	Tar	ESP Tar 0615 hrs
UMD-104	02-26-81	Tar	ESP Tar 1235 hrs
UMD-105	02-27-81	Tar	ESP Tar 1430 hrs
UMD-106	02-27-81	Tar	ESP Tar 1805 hrs
UMD-107	03-02-81	Tar	ESP Tar to Boiler 1615 hrs
UMD-108	03-02-81	Tar	ESP Tar to Boiler 1115 hrs
UMD-109	03-03-81	Tar	ESP Tar to Boiler 1240 hrs
UMD-110	03-03-81	Tar	ESP Tar to Boiler 1924 hrs
UMD-111	03-03-81	Tar	ESP Tar to Boiler 1140 hrs
UMD-112	02-24-81	Solid	Cyclone Dust 1050 hrs

(Continued)

TABLE A-8. (Continued)

Sample Number	Date	Sample Type	Sample Description or Parameter
UMD-113	02-24-81	Solid	Cyclone Dust 2000 hrs
UMD-114	02-24-81	Solid	Cyclone Dust 1345 hrs
UMD-115	02-25-81	Solid	Cyclone Dust app. 0100 hrs
UMD-116	02-25-81	Solid	Cyclone Dust app. 0100 hrs
UMD-117	02-26-81	Solid	Cyclone Dust 0630 hrs
UMD-118	02-26-81	Solid	Cyclone Dust 0240 hrs
UMD-119	02-27-81	Solid	Cyclone Dust 1120 hrs
UMD-120	02-27-81	Solid	Cyclone dust 1425 hrs
UMD-121	02-27-81	Solid	Cyclone Dust 1810 hrs
UMD-122	02-24-81	Solid	Gasifier Ash 1045 hrs
UMD-123	02-24-81	Solid	Gasifier Ash 1635 hrs
UMD-124	02-24-81	Solid	Gasifier Ash 2005 hrs
UMD-125	02-25-81	Solid	Gasifier Ash 0210 hrs
UMD-126	02-25-81	Solid	Gasifier Ash 0625 hrs
UMD-127	02-26-81	Solid	Gasifier Ash 0620 hrs
UMD-128	02-26-81	Solid	Gasifier Ash 1225 hrs
UMD-129	02-27-81	Solid	Gasifier Ash 1110 hrs
UMD-130	02-27-81	Solid	Gasifier Ash 1430 hrs
UMD-131	02-27-81	Solid	Gasifier Ash 1815 hrs
UMD-132	03-04-81	Gas	#3 Boiler Natural Gas SO_2 Run #1 Imp. #1
UMD-133	03-04-81	Gas	#3 Boiler Natural Gas SO_2 Run #1 Imp. #2
UMD-134	03-04-81	Gas	#3 Boiler Natural Gas SO_2 Run #1 Imp. #1
UMD-135	03-04-81	Gas	#3 Boiler Natural Gas SO_2 Run #2 Imp. #2
UMD-136	03-04-81	Gas	#3 Boiler Natural Gas SO_2 Run #3 Imp. #1
UMD-137	03-04-81	Gas	#3 Boiler Natural Gas SO_2 Run #3 Imp. #2
UMD-138	03-05-81	Gas	Raw Bottom Gas NH_3 Run #1 Imp. #1
UMD-139	03-05-81	Gas	Raw Bottom Gas NH_3 Run #1 Imp. #2
UMD-140	03-05-81	Gas	Cleaned Bottom Gas NH_3 Run #1 Imp. #1
UMD-141	03-05-81	Gas	Cleaned Bottom Gas NH_3 Run #1 Imp. #2
UMD-142	03-05-81	Gas	Raw Bottom Gas CN Run #1 Imp. #1
UMD-143	03-05-81	Gas	Raw Bottom Gas CN Run #1 Imp. #2
UMD-144	03-05-81	Gas	Cleaned Bottom Gas CN Run #1 Imp. #1
UMD-145	03-05-81	Gas	Cleaned Bottom Gas CN Run #1 Imp. #2
UMD-146	03-05-81	Gas	Raw Bottom Gas NH_3 Run #2 Imp. #1
UMD-147	03-05-81	Gas	Raw Bottom Gas NH_3 Run #2 Imp. #2

(Continued)

TABLE A-8. (Continued)

Sample Number	Date	Sample Type	Sample Description or Parameter
UMD-148	03-05-81	Gas	Cleaned Bottom Gas NH_3 Run #2 Imp. #1
UMD-149	03-05-81	Gas	Cleaned Bottom Gas NH_3 Run #2 Imp. #2
UMD-150	03-05-81	Gas	Raw Bottom Gas CN Run #2 Imp. #1
UMD-151	03-05-81	Gas	Raw Bottom Gas CN Run #2 Imp. #2
UMD-152	03-05-81	Gas	Cleaned Bottom Gas CN Run #2 Imp. #1
UMD-153	03-05-81	Gas	Cleaned Bottom Gas CN Run #2 Imp. #2
UMD-154	03-05-81	Gas	Cleaned Bottom Gas Trace Metals Imp. #1
UMD-155	03-05-81	Gas	Cleaned Bottom Gas Trace Metals Imp. #2
UMD-156	03-05-81	Gas	Raw Bottom Gas Trace Metals Imp. #1
UMD-157	03-05-81	Gas	Raw Bottom Gas Trace Metals Imp. #2
UMD-158	03-05-81	Water	Composite Ash Pan Water 1250, 1555, 2100 hrs
UMD-159	03-05-81	Gas	Cleaned Bottom Gas Trace Metals Imp. $MeCl_2$ Rinse
UMD-160	03-05-81	Gas	Raw Bottom Gas NH_3 Run #3 Imp. #1
UMD-161	03-05-81	Gas	Raw Bottom Gas NH_3 Run #3 Imp. #2
UMD-162	03-05-81	Gas	Cleaned Bottom Gas NH_3 Run #3 Imp. #1
UMD-163	03-05-81	Gas	Cleaned Bottom Gas NH_3 Run #3 Imp. #2
UMD-164	03-05-81	Gas	Raw Bottom Gas CN Run #3 Imp. #1
UMD-165	03-05-81	Gas	Raw Bottom Gas CN Run #3 Imp. #2
UMD-166	03-05-81	Gas	Cleaned Bottom Gas CN Run #3 Imp. #1
UMD-167	03-05-81	Gas	Cleaned Bottom Gas CN Run #3 Imp. #2
UMD-168	02-25-81	Gas	Organics, Combined Gas, Probe and Filter Rinse
UMD-169	02-25-81	Gas	Organics, Combined Gas, Condensate
UMD-170	02-27-81	Gas	ESP Precipitate - Raw Top Gas
UMD-171	02-27-81	Gas	Cleaned Top Gas, Condensate/Organics
UMD-172	02-27-81	Gas	Raw Top Gas, Probe Rinse
UMD-173	02-27-81	Gas	Raw Top Gas, ESP Rinse
UMD-174	02-27-81	Gas	Cleaned Top Gas, Probe Rinse/Organics
UMD-175	02-27-81	Gas	Cleaned Top Gas, Condenser Rinse/ Organics
UMD-176	02-27-81	Gas	Raw Top Gas, Condenser Rinse/Organics
UMD-177	02-27-81	Gas	Raw Top Gas, Resin/Organics
UMD-178	02-27-81	Gas	Raw Top Gas, Condensate/Organics
UMD-179	02-27-81	Gas	Cleaned Top Gas, XAD-2 Resin/Organics
UMD-180	02-27-81	Gas	Cleaned Top Gas, Filter/TM Run 2.9093 Tare
UMD-181	02-27-81	Gas	Cleaned Top Gas, Filter/Organics 2.8933 Tare
UMD-182	02-27-81	Gas	Cleaned Top Gas, XAD-2 Resin/Blank
UMD-183	02-27-81	Gas	Cleaned Top Gas, Impinger Rinse-$MeCl_2$/TM

(Continued)

TABLE A-8. (Continued)

Sample Number	Date	Sample Type	Sample Description or Parameter
UMD-184	03-03-81	Gas	Tar Stack, SASS Condensate 1 of 2
UMD-185	03-03-81	Gas	Tar Stack, SASS Condensate 2 of 2
UMD-186	03-03-81	Gas	Tar Stack, SASS Condenser Rinse
UMD-187	03-03-81	Gas	Tar Stack, SASS Probe Rinse
UMD-188	03-03-81	Gas	Tar Stack, SASS Probe Rinse
UMD-189	03-03-81	Gas	Tar Stack, SASS XAD Resin (Organics: 1 of 3)
UMD-190	03-03-81	Gas	Tar Stack, SASS Filter
UMD-191	03-03-81	Gas	Tar Stack, SASS Thimble
UMD-192	03-03-81	Gas	Tar Stack, SASS XAD Resin (2 of 3)
UMD-193	03-03-81	Gas	Tar Stack, SASS XAD Resin (3 of 3)
UMD-194	03-05-81	Gas	Cleaned Bottom Gas, Condensate/Organics
UMD-195	03-05-81	Gas	Raw Bottom Gas, Condenser Rinse/ Organics
UMD-196	03-05-81	Gas	Cleaned Bottom Gas
UMD-197	03-05-81	Gas	Raw Bottom Gas, XAD Resin Blank
UMD-198	03-05-81	Gas	Cleaned Bottom Gas, XAD
UMD-199	03-05-81	Gas	Cleaned Bottom Gas, Condenser Rinse
UMD-200	03-05-81	Gas	Raw Bottom Gas, XAD
UMD-201	03-06-81	Gas	Raw Bottom Gas #1, Nozzle and Probe Rinse
UMD-202	03-06-81	Gas	Cleaned Bottom Gas #14, Nozzle and Probe Rinse
UMD-203	03-06-81	Solid	Feed Coal 2040 hrs
UMD-204	02-26-81	Solid	Feed Coal 1250 hrs
UMD-205	02-26-81	Solid	Feed Coal 1810 hrs
UMD-206	03-05-81	Solid	Feed Coal 1240 hrs
UMD-207	03-05-81	Solid	Feed Coal 1540 hrs
UMD-208	03-05-81	Gas	XAD Resin Blank
UMD-209	03-05-81	Gas	Raw Bottom Gas Thimble
UMD-210	03-05-81	Gas	Cleaned Bottom Gas Thimble
UMD-211	03-05-81	Tar	ESP Tars 1550 hrs
UMD-212	03-05-81	Tar	ESP Tars 1245 hrs
UMD-213	03-05-81	Tar	ESP Tars 2045 hrs
UMD-214	03-05-81	Solid	Cyclone Dust 2055 hrs
UMD-215	03-05-81	Solid	Cyclone Dust 1600 hrs
UMD-216	03-05-81	Solid	Cyclone Dust 1255 hrs
UMD-217	03-05-81	Solid	Gasifier Ash 1300 hrs
UMD-218	03-05-81	Solid	Gasifier Ash 1603 hrs
UMD-219	03-05-81	Solid	Gasifier Ash 2100 hrs
UMD-220	03-05-81	Water	Service Water 1535 hrs

(Continued)

TABLE A-8. (Continued)

Sample Number	Date	Sample Type	Sample Description or Parameter
UMD-221		Gas	Trace Metals SASS Blank .2M Ammonium Persulfate, .02M Silver Nitrate
UMD-222		Gas	SO_2 Blank 6% H_2O_2
UMD-223	02-25-81	Gas	Main Stack Hg #1
UMD-224	02-25-81	Gas	Main Stack Hg #2
UMD-225	02-25-81	Gas	Combined Gas Hg #1
UMD-226	02-25-81	Gas	Combined Gas Hg #2
UMD-227	02-25-81	Gas	Tar Stack Hg #1
UMD-228	03-03-81	Gas	Tar Stack Hg #2
UMD-229	02-27-81	Solid	Coal 1035 hrs
UMD-230	02-27-81	Solid	Coal 1350 hrs
UMD-231	02-27-81	Solid	Coal 1825 hrs
UMD-232		Gas	Raw Top Gas, Thimble behind ESP 4.5878 Tare
UMD-233		Gas	Raw Bottom Gas, Condensate/Organics 26 mL
UMD-301	Aug. 81	Coal Composite	Composite Sample - Coal, 18.0 g dry, pulverized UMD-030, + 18.0 g dry, pulverized UMD-031, + 18.0 g dry, pulverized UMD-032
UMD-302	Aug. 81	Coal Composite	Composite Sample - Coal, 18.0 g UMD-229, + 18.0 g UMD-230, + 18.0 g UMD-231
UMD-303	Aug. 81	Coal Composite	Composite Sample - Coal, 18.0 g UMD-206 18.0 g UMD-207 18.0 g UMD-203
UMD-304	Aug. 81	Solids	Ash Pan Water 018,056 Filtered to Yield Solids Weighing 0.41478 g. Solids removed by Filtration (Millipore® Polycarbonate)
UMD-305	Aug. 81	Tar Composite	45 g UMD-105 + 45 g UMD-106
UMD-306	Aug. 81	Tar Composite	30 g UMD-212 + 30 g UMD-211 + 30 g UMD-213
UMD-307	Aug. 81	Tar Composite	40.5 g UMD-108 + 40.5 g UMD-109 + 40.5 g UMD-110
UMD-308	Aug. 81	Tar Composite	30.0 g UMD-100 + 30.0 g UMD-101 + 30.0 g UMD-102

(Continued)

TABLE A-8. (Continued)

Sample Number	Date	Sample Type	Sample Description or Parameter
UMD-309	Aug. 81	Cyclone Dust Composite	20 g each of UMD-114, 113, and 115/116
UMD-310	Aug. 81	Cyclone Dust Composite	20 g each of UMD-119, 120, 121
UMD-311	Aug. 81	Cyclone Dust Composite	20 g each of UMD-216, 215, 214
UMD-312	09-16-81	Gasifier Ash Composite	20 g each of UMD-124, 125, 126
UMD-313	09-16-81	Gasifier Ash Composite	20 g each of UMD-129, 130, 131
UMD-314	09-16-81	Gasifier Ash Composite	20 g each of UMD-217, 218, 219
UMD-315	10-01-81	Coal	Composite 20 g each of UMD-030, 031, 032, 229, 230, 231
UMD-316	10-01-81	Cyclone Dust	Composite 20 g each of UMD-113, 114, 115/116, 119, 120, 121
UMD-317	10-01-81	Gasifier Ash	Composite 20 g each of UMD-124, 125, 126, 129, 130, 131
UMD-318	10-01-81	Impinger Composite	Trace Metals Combined 17, UMD-051 Digested and added to UMD-049 Composite UMD-049 (with 051) 232 mL, 1/2 of total and UMD-050 72 mL, 1/2 of total
UMD-319	10-01-81	Impinger Composite	SASS #1 Main Stack UMD-068 239 mL, 1/4 of total; UMD-069 64 mL, 1/4 of total
UMD-320	10-01-81	Impinger Composite	Stub Stack SASS -- UMD-095 282 mL 1/4 of total UMD-096 74 mL 1/4 of total Main Stack
UMD-321	10-02-81	Solvent Extract Composite	SASS #1, $MeCl_2$ + Et_2O UMD-070 Resin & Rinse #1 UMD-078 Resin & Rinse #2
UMD-322	10-02-81	Solvent Extract Composite	Tar Stack SASS $MeCl_2$ + Et_2O UMD-189 XAD Resin/Organics UMD-192 XAD Resin/Organics UMD-193 XAD Resin/Organics

APPENDIX B

ANALYTICAL RESULTS

TABLE B-1. COAL MOISTURE

Sample Date	Sample Time	Concentration[1] %
2-24	1945	11.9
2-25	0145	11.2
2-25	0615	11.4
2-27	1035	11.0
2-27	1550	10.3
2-27	1825	10.8
3-5	1240	10.6
3-5	1540	11.1
3-5	2040	10.6
AVERAGE		11.0 ± 0.5

[1]Moisture determined by drying sample at 110°C and calculating weight loss.

TABLE B-2. GASIFIER ASH MOISTURE

Sample Date	Sample Time	Concentration[1] %
2-24	2005	23.1
2-25	0210	26.4
2-25	0625	24.9
2-27	1110	17.5
2-27	1430	21.3
2-27	1815	24.6
3-5	1300	28.1
3-5	1603	31.3
3-5	2100	27.0
AVERAGE		24.9 ± 4.0

[1]Moisture determined by drying sample at 110°C and calculating weight loss.

TABLE B-3. ESP OIL DENSITY

Composite Samples Date	Time	Density[1] g/mL
2-24	1640	
2-24	2005	0.905
2-25	0155	
2-27	1430	0.912
2-27	1805	
3-3	1115	
3-3	1249	0.911
3-3	1825	
3-5	1245	
3-5	1550	0.925
3-5	2045	
AVERAGE		0.913 ± 0.008

[1]Measured at 38°C (100°F).

} Composite sample.

TABLE B-4. RESULTS OF SSMS ANALYSIS OF XAD-2 RESIN BLANK

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 330 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 AREA CODE 312 726-8434

Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401 PHONE 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P. O. Box 9948
Austin, TX 78766

Date: October 19, 1981

Analyst: J. Oldham

P. O. No.: 8075

Sample No.: 208

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No. 97-H492-113-12

CONCENTRATION IN µg/mL

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	<0.001
Thorium		Gadolinium		Molybdenum	0.005	Titanium	0.05
Bismuth		Europium		Niobium	≤0.002	Scandium	<0.001
Lead	0.008	Samarium		Zirconium	≤0.003	Calcium	0.7
Thallium		Neodymium		Yttrium	≤0.003	Potassium	MC
Mercury	NR	Praseodymium		Strontium	0.005	Chlorine	1
Gold		Cerium		Rubidium	<0.001	Sulfur	1
Platinum		Lanthanum		Bromine	0.03	Phosphorus	0.02
Iridium		Barium	0.3	Selenium	0.006	Silicon	MC
Osmium		Cesium		Arsenic	0.002	Aluminum	0.01
Rhenium		Iodine	≤0.001	Germanium		Magnesium	0.09
Tungsten		Tellurium		Gallium	0.001	Sodium	>2
Tantalum		Antimony		Zinc	0.08	Fluorine	≈0.003
Hafnium		Tin		Copper	0.01	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.002	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	<0.001	Carbon	NR
Thulium		Silver		Iron	0.02	Boron	<0.001
Erbium		Palladium		Manganese	<0.001	Beryllium	
Holmium		Rhodium		Chromium	0.003	Lithium	0.001
Dysprosium						Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.001 µg/mL
MC — Major Component > 10 µg/mL
INT — Interference

Approved: [illegible]

TABLE B-5. RESULTS OF SSMS ANALYSIS OF TRACE METALS IMPINGERS SOLUTION

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434

Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401 PHONE 303-278-9521

To: Mr. Michael Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

Date: October 26, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: #221

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No.: 97-H492-113-12

CONCENTRATION IN µg/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	<0.001
Thorium		Gadolinium		Molybdenum		Titanium	0.06
Bismuth		Europium		Niobium		Scandium	≤0.002
Lead	0.01	Samarium		Zirconium	0.01	Calcium	0.6
Thallium		Neodymium		Yttrium	≤0.002	Potassium	3
Mercury	NR	Praseodymium		Strontium	0.009	Chlorine	1
Gold		Cerium		Rubidium		Sulfur	MC
Platinum		Lanthanum		Bromine	0.2	Phosphorus	0.3
Iridium		Barium	0.009	Selenium	≤0.01	Silicon	7
Osmium		Cesium		Arsenic		Aluminum	0.2
Rhenium		Iodine	0.002	Germanium		Magnesium	0.02
Tungsten		Tellurium		Gallium	≤0.002	Sodium	0.6
Tantalum		Antimony		Zinc	0.03	Fluorine	≈3
Hafnium		Tin		Copper	0.6	Oxygen	NR
Lutetium		Indium	STD	Nickel	*0.3	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.001	Carbon	NR
Thulium		Silver	MC	Iron	*MC	Boron	0.002
Erbium		Palladium		Manganese	*0.04	Beryllium	
Holmium		Rhodium		Chromium	0.2	Lithium	<0.001
Dysprosium						Hydrogen	NR

* Heterogeneous

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.002 µg/ml
MC — Major Component > 10 µg/ml
INT — Interference

Approved: M Jacobs

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TABLE B-6. RESULTS OF SSMS ANALYSIS OF ASH PAN WATER COMPOSITE

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434

Reply to INSTRUMENTAL ANALYSIS DIVISION, 14325 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P. O. Box 9948
Austin, TX 78766

Date: October 19, 1981

Analyst: J. Oldham

P. O. No.: 8075

Sample No.: 304

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No. 97-H492-113-12

CONCENTRATION IN µg/mL

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	≤0.01	Terbium		Ruthenium		Vanadium	0.001
Thorium	≤0.01	Gadolinium		Molybdenum	0.02	Titanium	0.2
Bismuth		Europium		Niobium	0.002	Scandium	≤0.002
Lead	0.01	Samarium		Zirconium	0.01	Calcium	MC
Thallium		Neodymium		Yttrium	0.05	Potassium	6
Mercury	NR	Praseodymium		Strontium	MC	Chlorine	0.7
Gold		Cerium		Rubidium	0.03	Sulfur	>9
Platinum		Lanthanum		Bromine	0.1	Phosphorus	0.1
Iridium		Barium	4	Selenium	0.04	Silicon	0.4
Osmium		Cesium	<0.001	Arsenic	0.03	Aluminum	0.03
Rhenium		Iodine	0.007	Germanium		Magnesium	0.3
Tungsten		Tellurium	0.004	Gallium	0.02	Sodium	0.2
Tantalum		Antimony		Zinc	0.04	Fluorine	≈0.05
Hafnium		Tin		Copper	0.02	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.002	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	0.005	Carbon	NR
Thulium		Silver		Iron	9	Boron	0.4
Erbium		Palladium		Manganese	<0.001	Beryllium	
Holmium		Rhodium		Chromium	0.04	Lithium	0.2
Dysprosium						Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.001 µg/mL
MC — Major Component > 10 µg/mL
INT — Interference

Approved:

TABLE B-7. RESULTS OF SSMS ANALYSIS OF ESP TAR TO BOILER NO. 3 COMPOSITE

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434

Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401 PHONE: 303-278-9521

To: Mr. Michael Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

Date: October 20, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: #307

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No. 97-H492-113-12

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	0.2
Thorium		Gadolinium		Molybdenum	0.02	Titanium	0.6
Bismuth	0.03	Europium		Niobium		Scandium	<0.01
Lead	0.4	Samarium		Zirconium	0.08	Calcium	12
Thallium		Neodymium		Yttrium		Potassium	3
Mercury	NR	Praseodymium	<0.01	Strontium	0.4	Chlorine	0.3
Gold		Cerium	0.06	Rubidium	0.02	Sulfur	8
Platinum		Lanthanum	0.05	Bromine	0.1	Phosphorus	3
Iridium		Barium	4	Selenium	≤0.03	Silicon	4
Osmium		Cesium		Arsenic	0.8	Aluminum	*>5
Rhenium		Iodine	0.06	Germanium	≤0.02	Magnesium	0.2
Tungsten		Tellurium		Gallium	0.07	Sodium	2
Tantalum		Antimony	<0.01	Zinc	*MC	Fluorine	≈4
Hafnium		Tin	0.04	Copper	0.07	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.09	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	<0.01	Carbon	NR
Thulium		Silver	*0.2	Iron	MC	Boron	0.02
Erbium		Palladium		Manganese	0.6	Beryllium	
Holmium		Rhodium		Chromium	0.6	Lithium	0.03
Dysprosium						Hydrogen	NR

* Heterogeneous

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.01ppm
MC — Major Component > 100ppm
INT — Interference

Approved: [illegible]

TABLE B-8. RESULTS OF SSMS ANALYSIS OF COAL COMPOSITE

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 330 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434

Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P. O. Box 9948
Austin, TX 78766

Date: October 19, 1981

Analyst: J. Oldham

P. O. No.: 8075

Sample No.: 315

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No.: 97-H492-113-12

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	3	Terbium		Ruthenium		Vanadium	14
Thorium	4	Gadolinium		Molybdenum	2	Titanium	890
Bismuth		Europium	0.2	Niobium	4	Scandium	1
Lead	3	Samarium	2	Zirconium	31	Calcium	MC
Thallium		Neodymium	0.9	Yttrium	14	Potassium	MC
Mercury	NR	Praseodymium	2	Strontium	MC	Chlorine	27
Gold		Cerium	11	Rubidium	4	Sulfur	MC
Platinum		Lanthanum	9	Bromine	2	Phosphorus	MC
Iridium		Barium	MC	Selenium	≤0.6	Silicon	MC
Osmium		Cesium	0.3	Arsenic	2	Aluminum	MC
Rhenium		Iodine	≤0.4	Germanium	≤0.2	Magnesium	870
Tungsten		Tellurium	0.4	Gallium	5	Sodium	>480
Tantalum		Antimony	0.9	Zinc	3	Fluorine	≈7
Hafnium		Tin	0.4	Copper	5	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.8	Nitrogen	NR
Ytterbium		Cadmium	1	Cobalt	1	Carbon	NR
Thulium		Silver	0.8	Iron	MC	Boron	8
Erbium		Palladium		Manganese	24	Beryllium	0.3
Holmium		Rhodium		Chromium	2	Lithium	12
Dysprosium						Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.2 ppm
MC — Major Component > 1,000 ppm
INT — Interference

Approved: [illegible]

TABLE B-9. RESULTS OF SSMS ANALYSIS OF CYCLONE DUST COMPOSITE

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 330 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434

Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P. O. Box 9948
Austin, TX 78766

Date: October 19, 1981

Analyst: J. Oldham

P. O. No.: 8075

Sample No.: 316

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No. 97-H492-113-12

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	7	Terbium	0.8	Ruthenium		Vanadium	30
Thorium	8	Gadolinium	2	Molybdenum	9	Titanium	MC
Bismuth	4	Europium	1	Niobium	10	Scandium	1
Lead	870	Samarium	4	Zirconium	55	Calcium	MC
Thallium	12	Neodymium	2	Yttrium	16	Potassium	MC
Mercury	NR	Praseodymium	5	Strontium	760	Chlorine	86
Gold		Cerium	28	Rubidium	9	Sulfur	MC
Platinum		Lanthanum	20	Bromine	7	Phosphorus	MC
Iridium		Barium	MC	Selenium	10	Silicon	MC
Osmium		Cesium	0.7	Arsenic	40	Aluminum	MC
Rhenium		Iodine	4	Germanium	19	Magnesium	MC
Tungsten	4	Tellurium	1	Gallium	280	Sodium	>480
Tantalum		Antimony	4	Zinc	560	Fluorine	MC
Hafnium	≤2	Tin	77	Copper	64	Oxygen	NR
Lutetium		Indium	STD	Nickel	3	Nitrogen	NR
Ytterbium		Cadmium	3	Cobalt	1	Carbon	NR
Thulium		Silver	≤2	Iron	MC	Boron	400
Erbium	0.8	Palladium		Manganese	97	Beryllium	0.8
Holmium	1	Rhodium		Chromium	220	Lithium	27
Dysprosium	4					Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.2 ppm
MC — Major Component > 1,000 ppm
INT — Interference

Approved:

TABLE B-10. RESULTS OF SSMS ANALYSIS OF GASIFIER ASH COMPOSITE

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8484
INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

Reply to

To: Mr. Michael R. Fuchs
Radian Corporation
P. O. Box 9948
Austin, TX 78766

Date: October 19, 1981

Analyst: J. Oldham

P. O. No.: 8075

Sample No.: 317

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No.: 97-H492-113-12

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	19	Terbium	1	Ruthenium		Vanadium	68
Thorium	29	Gadolinium	4	Molybdenum	3	Titanium	MC
Bismuth	≤0.1	Europium	1	Niobium	*38	Scandium	2
Lead	12	Samarium	6	Zirconium	*200	Calcium	MC
Thallium	0.4	Neodymium	19	Yttrium	50	Potassium	MC
Mercury	NR	Praseodymium	16	Strontium	MC	Chlorine	10
Gold		Cerium	99	Rubidium	59	Sulfur	>420
Platinum		Lanthanum	180	Bromine	3	Phosphorus	MC
Iridium		Barium	MC	Selenium	0.8	Silicon	MC
Osmium		Cesium	8	Arsenic	1	Aluminum	MC
Rhenium		Iodine	0.3	Germanium	0.7	Magnesium	MC
Tungsten	2	Tellurium	0.2	Gallium	23	Sodium	>170
Tantalum	0.6	Antimony	1	Zinc	2	Fluorine	≈110
Hafnium	2	Tin	0.5	Copper	23	Oxygen	NR
Lutetium	0.3	Indium	STD	Nickel	3	Nitrogen	NR
Ytterbium	2	Cadmium	5	Cobalt	1	Carbon	NR
Thulium	0.2	Silver	≤0.3	Iron	MC	Boron	64
Erbium	3	Palladium		Manganese	230	Beryllium	0.9
Holmium	4	Rhodium		Chromium	8	Lithium	64
Dysprosium	6	*Heterogeneous				Hydrogen	NR

STD – Internal Standard
NR – Not Reported
All elements not detected < 0.1 ppm
MC – Major Component > 1,000 ppm
INT – Interference

Approved:

TABLE B-11. RESULTS OF SSMS ANALYSIS OF COMBINED GAS TRACE METALS IMPINGERS COMPOSITE

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 330 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8484

Reply to INSTRUMENTAL ANALYSIS DIVISION: 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE 303-278-9521

To: Mr. Michael Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

Date: October 26, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: #318

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No. 97-H492-113-12

CONCENTRATION IN µg/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	0.002
Thorium		Gadolinium		Molybdenum		Titanium	0.04
Bismuth		Europium		Niobium		Scandium	<0.001
Lead		Samarium		Zirconium	0.02	Calcium	2
Thallium		Neodymium		Yttrium		Potassium	MC
Mercury	NR	Praseodymium		Strontium	0.006	Chlorine	2
Gold		Cerium		Rubidium	0.003	Sulfur	2
Platinum		Lanthanum		Bromine	0.3	Phosphorus	0.5
Iridium		Barium		Selenium	≤0.02	Silicon	4
Osmium		Cesium		Arsenic	0.06	Aluminum	0.4
Rhenium		Iodine		Germanium		Magnesium	0.6
Tungsten		Tellurium		Gallium	≤0.003	Sodium	3
Tantalum		Antimony		Zinc	0.5	Fluorine	≈2
Hafnium		Tin		Copper	0.4	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.2	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.005	Carbon	NR
Thulium		Silver	MC	Iron	0.7	Boron	0.3
Erbium		Palladium		Manganese	0.06	Beryllium	
Holmium		Rhodium		Chromium	0.3	Lithium	0.1
Dysprosium						Hydrogen	NR

STD – Internal Standard
NR – Not Reported
All elements not detected < 0.003 µg/ml
MC – Major Component > 10 µg/ml
INT – Interference

Approved: M Specht

TABLE B-12. RESULTS OF SSMS ANALYSIS OF MAIN STACK SASS IMPINGERS COMPOSITE

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 330 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434

Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE 303-278-9521

To: Mr. Michael Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

Date: October 26, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: #319

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No. 97-H492-113-12

CONCENTRATION IN µg/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	
Thorium		Gadolinium		Molybdenum		Titanium	0.06
Bismuth		Europium		Niobium		Scandium	≤0.002
Lead	0.009	Samarium		Zirconium	0.008	Calcium	2
Thallium		Neodymium		Yttrium		Potassium	MC
Mercury	NR	Praseodymium		Strontium	0.01	Chlorine	0.6
Gold		Cerium		Rubidium		Sulfur	>8
Platinum		Lanthanum		Bromine	0.3	Phosphorus	0.2
Iridium		Barium	0.03	Selenium	0.008	Silicon	4
Osmium		Cesium		Arsenic		Aluminum	1
Rhenium		Iodine	0.003	Germanium		Magnesium	0.06
Tungsten		Tellurium		Gallium	0.007	Sodium	>3
Tantalum		Antimony		Zinc	0.4	Fluorine	≈0.5
Hafnium		Tin		Copper	0.02	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.02	Nitrogen	NR
Ytterbium		Cadmium	0.004	Cobalt	<0.001	Carbon	NR
Thulium		Silver	MC	Iron	0.3	Boron	0.003
Erbium		Palladium		Manganese	0.005	Beryllium	
Holmium		Rhodium		Chromium	0.01	Lithium	<0.001
Dysprosium						Hydrogen	NR

STD – Internal Standard
NR – Not Reported
All elements not detected < 0.001 µg/ml
MC – Major Component > 10 µg/ml
INT – Interference

Approved: M Jacobs

TABLE B-13. RESULTS OF SSMS ANALYSIS OF BOILER NO. 3 SASS IMPINGERS COMPOSITE

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434

Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE 303-278-9521

To: Mr. Michael Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

Date: October 26, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: #320

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No. 97-H492-113-12

CONCENTRATION IN µg/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	0.001
Thorium		Gadolinium		Molybdenum		Titanium	0.04
Bismuth		Europium		Niobium		Scandium	<0.001
Lead		Samarium		Zirconium		Calcium	1
Thallium		Neodymium		Yttrium		Potassium	1
Mercury	NR	Praseodymium		Strontium	0.003	Chlorine	0.09
Gold		Cerium		Rubidium		Sulfur	3
Platinum		Lanthanum		Bromine	0.1	Phosphorus	0.1
Iridium		Barium		Selenium	0.002	Silicon	4
Osmium		Cesium		Arsenic		Aluminum	0.2
Rhenium		Iodine		Germanium		Magnesium	0.7
Tungsten		Tellurium		Gallium	<0.001	Sodium	0.8
Tantalum		Antimony		Zinc	0.1	Fluorine	≈0.05
Hafnium		Tin		Copper	0.02	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.2	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.002	Carbon	NR
Thulium		Silver	MC	Iron	2	Boron	0.001
Erbium		Palladium		Manganese	0.04	Beryllium	
Holmium		Rhodium		Chromium	0.9	Lithium	0.002
Dysprosium						Hydrogen	NR

STD – Internal Standard
NR – Not Reported
All elements not detected < 0.001 µg/ml
MC – Major Component > 10 µg/ml
INT – Interference

Approved: M J Jacobs

TABLE B-14. RESULTS OF SSMS ANALYSIS OF MAIN STACK SASS XAD-2 RESIN AND RINSE

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434

Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE 303-278-9521

To: Michael Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

Date: October 20, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: #321

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No.: 97-H492-113-12

CONCENTRATION IN µg/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	0.006
Thorium		Gadolinium		Molybdenum	0.01	Titanium	0.03
Bismuth		Europium		Niobium	≤0.003	Scandium	≤0.002
Lead		Samarium		Zirconium	0.003	Calcium	MC
Thallium		Neodymium		Yttrium	≤0.002	Potassium	*9
Mercury	NR	Praseodymium		Strontium	0.08	Chlorine	*1
Gold		Cerium		Rubidium	0.002	Sulfur	*0.2
Platinum		Lanthanum		Bromine	0.5	Phosphorus	0.04
Iridium		Barium	2	Selenium		Silicon	MC
Osmium		Cesium		Arsenic	0.002	Aluminum	0.03
Rhenium		Iodine	<0.001	Germanium		Magnesium	0.09
Tungsten		Tellurium		Gallium	0.002	Sodium	*3
Tantalum		Antimony		Zinc	0.06	Fluorine	≈0.3
Hafnium		Tin		Copper	*MC	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.02	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.002	Carbon	NR
Thulium		Silver		Iron	0.1	Boron	0.008
Erbium		Palladium		Manganese	0.003	Beryllium	
Holmium		Rhodium		Chromium	0.001	Lithium	0.008
Dysprosium						Hydrogen	NR

* Heterogeneous

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.002 µg/ml
MC — Major Component > 10 µg/ml
INT — Interference

Approved: [illegible]

TABLE B-15. RESULTS OF SSMS ANALYSIS OF BOILER NO. 3 STACK SASS XAD-2 RESIN AND RINSE

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434

Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Michael Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

Date: October 20, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: #322

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No.: 97-H492-113-12

CONCENTRATION IN µg/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	<0.001
Thorium		Gadolinium		Molybdenum	*0.002	Titanium	0.09
Bismuth		Europium		Niobium		Scandium	<0.001
Lead	0.01	Samarium		Zirconium	0.01	Calcium	0.7
Thallium		Neodymium		Yttrium		Potassium	0.06
Mercury	NR	Praseodymium		Strontium	0.004	Chlorine	0.3
Gold		Cerium		Rubidium		Sulfur	0.03
Platinum		Lanthanum		Bromine	0.04	Phosphorus	0.03
Iridium		Barium	0.005	Selenium	0.006	Silicon	0.07
Osmium		Cesium		Arsenic	0.001	Aluminum	0.03
Rhenium		Iodine		Germanium		Magnesium	0.02
Tungsten		Tellurium		Gallium	≤0.003	Sodium	0.01
Tantalum		Antimony		Zinc	0.02	Fluorine	≈0.2
Hafnium		Tin		Copper	0.006	Oxygen	NR
Lutetium		Indium	STD	Nickel	<0.001	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	<0.001	Carbon	NR
Thulium		Silver		Iron	0.01	Boron	<0.001
Erbium		Palladium		Manganese	<0.001	Beryllium	
Holmium		Rhodium		Chromium	0.002	Lithium	<0.001
Dysprosium						Hydrogen	NR

* Heterogeneous

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.002 µg/ml
MC — Major Component > 10µg/ml
INT — Interference

Approved: [illegible]

TABLE B-16. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF COAL

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 336 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 AREA CODE 312 726-5434

SINCE 1916

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

IAD No.: 97-H491-113-13

Date: November 9, 1981
Purchase Order: 8075
Sample I.D.: #301 Solid

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	3.33	xxxx
% Ash	8.58	8.88
% Volatile	35.98	37.22
% Fixed Carbon	52.11	53.90
	100.00	100.00
Btu/lb	11740	12144
% Sulfur	0.47	0.49

Moisture, Ash-free Btu 13327
% Moisture, Ash-free Volatile 40.85

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	3.33	xxxx
% Carbon	67.95	70.29
% Hydrogen	4.49	4.64
% Nitrogen	1.38	1.43
% Chlorine	0.00	0.00
% Sulfur	0.47	0.49
% Ash	8.58	8.88
% Oxygen (diff)	13.80	14.27
	100.00	100.00

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-17. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF COAL

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766
IAD No.: 97-H491-113-13

Date: November 9, 1981
Purchase Order: 8075
Sample I.D.: #302 Solid

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	4.18	xxxx
% Ash	11.33	11.82
% Volatile	35.11	36.64
% Fixed Carbon	49.38	51.54
	100.00	100.00
Btu/lb	11184	11672
% Sulfur	0.53	0.55

Moisture, Ash-free Btu 13237
% Moisture, Ash-free Volatile 41.55

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	4.18	xxxx
% Carbon	65.09	67.93
% Hydrogen	4.24	4.43
% Nitrogen	1.36	1.42
% Chlorine	0.00	0.00
% Sulfur	0.53	0.55
% Ash	11.33	11.82
% Oxygen (diff)	13.27	13.85
	100.00	100.00

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-18. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF COAL

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-9434

SINCE 1909

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

IAD No.: 97-H491-113-13

Date: November 9, 1981
Purchase Order: 8075
Sample I.D.: #303 Solid

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	4.08	xxxx
% Ash	7.50	7.82
% Volatile	35.07	36.56
% Fixed Carbon	53.35	55.62
	100.00	100.00
Btu/lb	11721	12220
% Sulfur	0.49	0.51

Moisture, Ash-free Btu 13257
% Moisture, Ash-free Volatile 39.66

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	4.08	xxxx
% Carbon	68.52	71.43
% Hydrogen	4.35	4.53
% Nitrogen	1.45	1.51
% Chlorine	0.00	0.00
% Sulfur	0.49	0.51
% Ash	7.50	7.82
% Oxygen (diff)	13.61	14.20
	100.00	100.00

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-19. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF ESP OIL

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 233 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 AREA CODE 312 726-2434

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

IAD No.: 97-H491-113-13

Date: November 10, 1981

Purchase Order: 8075

Sample I.D.: #305 Tar

PROXIMATE ANALYSIS

*% Weight Loss	0.60
% Ash	0.18
% Volatile	99.38
% Fixed Carbon	0.44
	100.60

ULTIMATE ANALYSIS

*% Weight Loss	0.60
% Carbon	85.11
% Hydrogen	10.88
% Nitrogen	0.44
% Sulfur	0.20
% Ash	0.18
% Oxygen	3.43
	100.84

% Sulfur 0.20
** Btu/lb 18959

* Weight loss: Sample dried at 105°C for one hour
** Btu calculated by Dulong formula

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-20. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF ESP OIL

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-5434

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

IAD No.: 97-H491-113-13

Date: November 10, 1981

Purchase Order: 8075

Sample I.D.: #306 Tar

PROXIMATE ANALYSIS	
*% Weight Loss	0.60
% Ash	0.11
% Volatile	94.99
% Fixed Carbon	4.90
	100.60

ULTIMATE ANALYSIS	
*% Weight Loss	0.60
% Carbon	83.85
% Hydrogen	9.91
% Nitrogen	0.97
% Sulfur	0.31
% Ash	0.11
% Oxygen	4.34
	100.09

% Sulfur	0.31
** Btu/lb	18101

* Weight loss: Sample dried at 105°C for one hour.

** Btu calculated by Dulong formula

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-21. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF ESP OIL

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8484

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

IAD No.: 97-H491-113-13

Date: November 10, 1981

Purchase Order: 8075

Sample I.D.: #308 Tar

PROXIMATE ANALYSIS

*% Weight Loss	0.45
% Ash	<0.10
% Volatile	99.52
% Fixed Carbon	0.48
	100.55

ULTIMATE ANALYSIS

*% Weight Loss	0.45
% Carbon	85.06
% Hydrogen	10.84
% Nitrogen	0.32
% Sulfur	0.21
% Ash	<0.10
% Oxygen	3.41
	100.39

% Sulfur	0.21
** Btu/lb	18928

* Weight loss: Sample dried at 105°C for one hour.
** Btu calculated by Dulong formula

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-22. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF ESP OIL TO BOILER NO. 3

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 AREA CODE 312 726-9434

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

IAD No.: 97-H491-113-13

Date: November 10, 1981

Purchase Order: 8075

Sample I.D.: #307 Tar

PROXIMATE ANALYSIS	
* % Weight Loss	0.45
% Ash	0.18
% Volatile	97.99
% Fixed Carbon	1.83
	100.45

ULTIMATE ANALYSIS	
* % Weight Loss	0.45
% Carbon	85.13
% Hydrogen	10.82
% Nitrogen	0.48
% Sulfur	0.24
% Ash	0.18
% Oxygen	3.36
	100.66

% Sulfur	0.24
** Btu/lb	18930

* Weight loss: Sample dried at 105°C for one hour.
** Btu calculated by Dulong formula

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-23. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF CYCLONE DUST

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 225 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 AREA CODE 312 726-0434

SINCE 1908

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

IAD No.: 97-H491-113-13

Date: November 6, 1981
Purchase Order: 8075
Sample I.D.: #309 Solid

PROXIMATE ANALYSIS	As Received	Dry Basis
% Moisture	1.55	xxxx
% Ash	23.98	24.36
% Volatile	2.54	2.58
% Fixed Carbon	71.93	73.06
	100.00	100.00
Btu/lb	10479	10644
% Sulfur	0.84	0.85

ULTIMATE ANALYSIS	As Received	Dry Basis
% Moisture	1.55	xxxx
% Carbon	71.94	73.07
% Hydrogen	0.77	0.78
% Nitrogen	0.80	0.81
% Chlorine	0.01	0.01
% Sulfur	0.84	0.85
% Ash	23.98	24.36
% Oxygen (diff)	0.11	0.12
	100.00	100.00

Moisture, Ash-free Btu 14075
% Moisture, Ash-free Volatile 3.41

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-24. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF CYCLONE DUST

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-5434

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766
IAD No.: 97-H491-113-13

Date: November 6, 1981
Purchase Order: 8075
Sample I.D.: #310 Solid

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	1.25	xxxx
% Ash	28.48	28.84
% Volatile	2.03	2.06
% Fixed Carbon	68.24	69.10
	100.00	100.00
Btu/lb	9922	10048
% Sulfur	0.87	0.88

Moisture, Ash-free Btu 14120
% Moisture, Ash-free Volatile 2.89

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	1.25	xxxx
% Carbon	69.51	70.39
% Hydrogen	0.55	0.56
% Nitrogen	0.66	0.67
% Chlorine	0.01	0.01
% Sulfur	0.87	0.88
% Ash	28.48	28.84
% Oxygen (diff)	-1.33	-1.35
	100.00	100.00

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-25. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF CYCLONE DUST

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-5434

SINCE 1898

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766
IAD No.: 97-H491-113-13

Date: November 9, 1981
Purchase Order: 8075
Sample I.D.: #311 Solid

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	1.00	xxxx
% Ash	27.53	27.81
% Volatile	2.53	2.56
% Fixed Carbon	68.94	69.63
	100.00	100.00
Btu/lb	9883	9983
% Sulfur	1.25	1.26

Moisture, Ash-free Btu 13829
% Moisture, Ash-free Volatile 3.55

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	1.00	xxxx
% Carbon	69.74	70.44
% Hydrogen	0.64	0.65
% Nitrogen	0.68	0.69
% Chlorine	0.01	0.01
% Sulfur	1.25	1.26
% Ash	27.53	27.81
% Oxygen (diff)	-0.85	-0.86
	100.00	100.00

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-26. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF GASIFIER ASH

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-6434

SINCE 1908

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766

IAD No.: 97-H491-113-13

Date: November 9, 1981
Purchase Order: 8075
Sample I.D.: #312 Solid

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	1.13	xxxx
% Ash	76.21	77.08
% Volatile	3.25	3.29
% Fixed Carbon	19.41	19.63
	100.00	100.00
Btu/lb	2950	2984
% Sulfur	0.27	0.27

Moisture, Ash-free Btu 13020
% Moisture, Ash-free Volatile 14.35

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	1.13	xxxx
% Carbon	20.40	20.63
% Hydrogen	0.11	0.11
% Nitrogen	0.24	0.24
% Chlorine	0.00	0.00
% Sulfur	0.27	0.27
% Ash	76.21	77.08
% Oxygen (diff)	1.64	1.67
	100.00	100.00

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-27. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF GASIFIER ASH

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 230 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-9434

SINCE 1896

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766
IAD No.: 97-H491-113-13

Date: November 9, 1981
Purchase Order: 8075
Sample I.D.: #313 Solid

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	1.80	xxxx
% Ash	69.08	70.35
% Volatile	3.25	3.31
% Fixed Carbon	25.87	26.34
	100.00	100.00
Btu/lb	3380	3442
% Sulfur	0.25	0.25

Moisture, Ash-free Btu 11609
% Moisture, Ash-free Volatile 11.16

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	1.80	xxxx
% Carbon	26.37	26.85
% Hydrogen	0.20	0.20
% Nitrogen	0.24	0.24
% Chlorine	0.01	0.01
% Sulfur	0.25	0.25
% Ash	69.08	70.35
% Oxygen (diff)	2.05	2.10
	100.00	100.00

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-28. RESULTS OF PROXIMATE AND ULTIMATE ANALYSIS OF GASIFIER ASH

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434

Reply to
Instrument Analysis Division
490 Orchard Street
Golden, CO 80401

Phone: 303-278-9521

To: Mr. Michael R. Fuchs
Radian Corporation
P.O. Box 9948
Austin, TX 78766
IAD No.: 97-H491-113-13

Date: November 9, 1981
Purchase Order: 8075
Sample I.D.: #314 Solid

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.81	xxxx
% Ash	85.00	85.69
% Volatile	4.80	4.84
% Fixed Carbon	9.39	9.47
	100.00	100.00
Btu/lb	1695	1709
% Sulfur	0.32	0.32

Moisture, Ash-free Btu 11943
% Moisture, Ash-free Volatile 33.82

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.81	xxxx
% Carbon	14.20	14.32
% Hydrogen	0.18	0.18
% Nitrogen	0.10	0.10
% Chlorine	0.00	0.00
% Sulfur	0.32	0.32
% Ash	85.00	85.69
% Oxygen (diff)	-0.61	-0.61
	100.00	100.00

M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Div.

Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

TABLE B-29. RESULTS OF SSMS, ICPES, AND AAS ELEMENTAL ANALYSIS OF COAL[1]

	SSMS	ICPES	AAS		SSMS	ICPES	AAS
Aluminum	>1000	1.3%		Neodymium	0.9		
Antimony	0.9		<0.2	Nickel	0.8	4.6	
Arsenic	2		1.8	Niobium	4		
Barium	>1000	480		Osmium	ND		
Beryllium	0.3			Palladium	ND		
Bismuth	ND			Phosphorus	>1000		
Boron	8	25		Platinum	ND		
Bromine	2			Potassium	>1000	950	
Cadmium	1			Praseodymium	2		
Calcium	>1000	3300		Rhenium	ND		
Cerium	11			Rhodium	ND		
Cesium	0.3			Rubidium	4		
Chlorine	27			Ruthenium	ND		
Chromium	2	5.2		Samarium	2		
Cobalt	1	1.6		Scandium	1		
Copper	5	4.8		Selenium	<0.6		0.36
Dysprosium	ND			Silicon	>1000		
Erbium	ND			Silver	0.8		
Europium	ND			Sodium	>480	180	
Fluorine	7			Strontium	>1000		
Gadolinium	ND			Sulfur[2]	>1000		
Gallium	5			Tantalum	ND		
Germanium	<0.2			Tellurium	0.4		
Gold	ND			Terbium	ND		
Hafnium	ND			Thallium	ND		
Holmium	ND			Thorium	4		
Iodine	<0.4			Thulium	ND		
Iridium	ND			Tin	0.4		
Iron	>1000	3600		Titanium	890	440	
Lanthanum	9			Tungsten	ND		
Lead	3			Uranium	3		
Lithium	12			Vanadium	14	9.7	
Lutetium	ND			Ytterbium	ND		
Magnesium	870	760		Yttrium	14		
Manganese	24	24		Zinc	3	5.1	
Mercury	NR		<0.07	Zirconium	31		
Molybdenum	2	2.9					

[1]Concentration in μg/g.
[2]Ultimate analysis value 0.52%.
NOTE: ICPES and AAS analyses performed in duplicate except for mercury. SSMS results of single analysis.
ND - not detected.
NR - no record.

TABLE B-30. RESULTS OF SSMS, ICPES, AND AAS ANALYSIS OF GASIFIER ASH[1]

	SSMS	ICPES	AAS		SSMS	ICPES	AAS
Aluminum	>1000	7.8%		Neodymium	19		
Antimony	1		<0.2	Nickel	3	31	
Arsenic	1		24	Niobium	38		
Barium	>1000	3300		Osmium	ND		
Beryllium	0.9			Palladium	ND		
Bismuth	<0.1			Phosphorus	>1000		
Boron	64	690		Platinum	ND		
Bromine	3			Potassium	>1000	8200	
Cadmium	5			Praseodymium	16		
Calcium	>1000	5%		Rhenium	ND		
Cerium	99			Rhodium	ND		
Cesium	8			Rubidium	59		
Chlorine	10			Ruthenium	ND		
Chromium	8	42		Samarium	6		
Cobalt	1	12		Scandium	2		
Copper	23	32		Selenium	0.8		0.6
Dysprosium	6			Silicon	>1000		
Erbium	3			Silver	<0.3		
Europium	1			Sodium	>170	1500	
Fluorine	110			Strontium	>1000		
Gadolinium	4			Sulfur[2]	>420		
Gallium	23			Tantalum	0.6		
Germanium	0.7			Tellurium	0.2		
Gold	ND			Terbium	1		
Hafnium	2			Thallium	0.4		
Holmium	4			Thorium	29		
Iodine	0.3			Thulium	0.2		
Iridium	ND			Tin	0.5		
Iron	>1000	4.0%		Titanium	>1000	1800	
Lanthanum	180			Tungsten	2		
Lead	12			Uranium	19		
Lithium	64			Vanadium	68	66	
Lutetium	0.3			Ytterbium	2		
Magnesium	>1000	1.2%		Yttrium	50		
Manganese	230	440		Zinc	2	15	
Mercury	NR		0.30	Zirconium	200		
Molybdenum	3	16					

[1]Concentration in μg/g.
[2]Ultimate analysis value 0.28%.
NOTE: All ICPES and AAS analyses performed in duplicate except for mercury. SSMS results of single analysis.
ND - not detected.
NR - no record.

TABLE B-31. RESULTS OF SSMS, ICPES, AND AAS ELEMENTAL ANALYSIS OF CYCLONE DUST[1]

	SSMS	ICPES	AAS		SSMS	ICPES	AAS
Aluminum	>1000	2.6%		Neodymium	2		
Antimony	4		19	Nickel	3	16	
Arsenic	40		31	Niobium	10		
Barium	>1000	320		Osmium	ND		
Beryllium	0.8			Palladium	ND		
Bismuth	4			Phosphorus	>1000		
Boron	400	98		Platinum	ND		
Bromine	7			Potassium	>1000	2700	
Cadmium	3			Praseodymium	5		
Calcium	>1000	1.2%		Rhenium	ND		
Cerium	28			Rhodium	ND		
Cesium	0.7			Rubidium	9		
Chlorine	86			Ruthenium	ND		
Chromium	220	20		Samarium	4		
Cobalt	1	4.3		Scandium	1		
Copper	64	22		Selenium	10		2.6
Dysprosium	4			Silicon	>1000		
Erbium	0.8			Silver	<2		
Europium	1			Sodium	>480	690	
Fluorine	>1000			Strontium	760		
Gadolinium	2			Sulfur[2]	>1000		
Gallium	280			Tantalum	ND		
Germanium	19			Tellurium	1		
Gold	<0.2			Terbium	0.8		
Hafnium	≤2			Thallium	12		
Holmium	1			Thorium	8		
Iodine	4			Thulium	ND		
Iridium	ND			Tin	77		
Iron	>1000	1.2%		Titanium	>1000	780	
Lanthanum	20			Tungsten	4		
Lead	870			Uranium	7		
Lithium	27			Vanadium	30	24	
Lutetium	ND			Ytterbium	ND		
Magnesium	>1000	2400		Yttrium	16		
Manganese	97	48		Zinc	560	620	
Mercury	NR		0.75	Zirconium	55		
Molybdenum	9	7.6					

[1]Concentration in μg/g.
[2]Ultimate analysis result 1.0%.
NOTE: ICPES and AAS analyses performed in duplicate except for mercury. SSMS results of single analysis.
ND - not detected.
NR - no record.

TABLE B-32. RESULTS OF SSMS, ICPES, AND AAS ELEMENTAL ANALYSIS OF ESP OIL[1]

	SSMS	ICPES	AAS		SSMS	ICPES	AAS
Aluminum	>5	54		Neodymium	ND		
Antimony	<0.01		0.2	Nickel	0.09	<0.3	
Arsenic	0.8		0.82	Niobium	ND		
Barium	4	5.2		Osmium	ND		
Beryllium	ND			Palladium	ND		
Bismuth	0.03			Phosphorus	3		
Boron	0.02	<1		Platinum	ND		
Bromine	0.1			Potassium	3	28	
Cadmium	ND			Praseodymium	<0.01		
Calcium	12	30		Rhenium	ND		
Cerium	0.06			Rhodium	ND		
Cesium	ND			Rubidium	0.02		
Chlorine	0.3			Ruthenium	ND		
Chromium	0.6	170		Samarium	ND		
Cobalt	<0.01	<0.6		Scandium	<0.01		
Copper	0.07	0.17		Selenium	≤0.03		<0.3
Dysprosium	ND			Silicon	4		
Erbium	ND			Silver	0.2		
Europium	ND			Sodium	2	49	
Fluorine	4			Strontium	0.4		
Gadolinium	ND			Sulfur[2]	8		
Gallium	0.07			Tantalum	ND		
Germanium	≤0.02			Tellurium	ND		
Gold	ND			Terbium	ND		
Hafnium	ND			Thallium	ND		
Holmium	ND			Thorium	ND		
Iodine	0.06			Thulium	ND		
Iridium	ND			Tin	0.04		
Iron	>100	170		Titanium	0.6	3.3	
Lanthanum	0.05			Tungsten	ND		
Lead	0.4			Uranium	ND		
Lithium	0.03			Vanadium	0.2	2.6	
Lutetium	ND			Ytterbium	ND		
Magnesium	0.2	<5.4		Yttrium	ND		
Manganese	0.6	0.54		Zinc	>100	0.72	
Mercury	NR		0.16	Zirconium	0.08		
Molybdenum	0.02	0.65					

[1]Concentration in μg/g.
[2]Ultimate analysis value is 0.24%.
NOTE: ICPES and AAS analyses performed in duplicate except for mercury. SSMS results of single analysis.
ND - not detected.
NR - no record.

TABLE B-33. RESULTS OF SSMS, ICPES, AND AAS ELEMENTAL ANALYSIS OF ASH PAN WATER[1]

	SSMS	ICPES	AAS		SSMS	ICPES	AAS
Aluminum	0.03	0.36		Neodymium	ND		
Antimony	ND		<0.002	Nickel	0.002	0.02	
Arsenic	0.03		<0.002	Niobium	0.002		
Barium	4	1.5		Osmium	ND		
Beryllium	ND			Palladium	ND		
Bismuth	ND			Phosphorus	0.1		
Boron	0.4	4.4		Platinum	ND		
Bromine	0.1			Potassium	6	13	
Cadmium	ND			Praseodymium	ND		
Calcium	>10		610	Rhenium	ND		
Cerium	ND			Rhodium	ND		
Cesium	<0.001			Rubidium	0.03		
Chlorine	0.7			Ruthenium	ND		
Chromium	0.04	0.05		Samarium	ND		
Cobalt	0.005	0.02		Scandium	<0.002		
Copper	0.02	0.06		Selenium	0.04		<0.003
Dysprosium	ND			Silicon	0.4		
Erbium	ND			Silver	ND		
Europium	ND			Sodium	0.2	4.5	
Fluorine	0.05			Strontium	>10		
Gadolinium	ND			Sulfur	>9		
Gallium	0.02			Tantalum	ND		
Germanium	ND			Tellurium	0.004		
Gold	ND			Terbium	ND		
Hafnium	ND			Thallium	ND		
Holmium	ND			Thorium	≤0.01		
Iodine	0.007			Thulium	ND		
Iridium	ND			Tin	ND		
Iron	9	<0.008		Titanium	0.2	0.14	
Lanthanum	ND			Tungsten	ND		
Lead	0.01			Uranium	≤0.01		
Lithium	0.2			Vanadium	0.001	0.11	
Lutetium	ND			Ytterbium	ND		
Magnesium	0.3	0.28		Yttrium	0.05		
Manganese	<0.001	0.008		Zinc	0.04	0.009	
Mercury	NR		0.0042	Zirconium	0.01		
Molybdenum	0.02	0.12					

[1]Concentration in μg/mL.
NOTE: ICPES and AAS analyses performed in duplicate except for mercury. SSMS results of single analysis.
ND - not detected.
NR - no record.

B.34 Elemental Analysis of the Combined Product Gas

Table B-34 presents the results of SSMS, AAS, and ICPES analyses of the combined product gas. The results for each method of analysis includes contributions from the impinger solutions, particulate, and oil loadings. The contribution of elements in the particulate was calculated by equating the elemental concentrations in the particulate load (1.95E5 $\mu g/Nm^3$) with the elemental concentrations in an identical mass of cyclone dust. The contribution of elements in the oil was calculated by equating the elemental concentrations in the oil load (2.0E4 $\mu g/Nm^3$) with the elemental concentrations in an identical mass of ESP oil. These results were added to the analytical results of the impinger solutions to determine the elemental concentrations in the combined product gas.

B.35 Elemental Analysis of Combustion Emissions from the Product Gas Boilers

The results of the analysis of impinger solutions, XAD-2 resin, and particulate loading for the combustion emissions from the product gas boilers are presented in Table B-35. The elemental concentrations for the particulate loading were calculated by equating the particulate concentration in the emission stream (3.9E4 $\mu g/Nm^3$) to cyclone dust, as described above.

B.36 Elemental Analysis of the Combustion Emissions from Boiler No. 3 Firing ESP Oils

Table B-36 presents the results of elemental analysis of impinger solutions, XAD-2 resin, and aerosol loading for the combustion emissions from Boiler No. 3 firing ESP oils. The elemental concentrations for the aerosol loading were calculated by equating the particulate concentration in the emission stream (4.8E4 $\mu g/Nm^3$) to cyclone dust and the oil loading (1.0E3 $\mu g/Nm^3$ to ESP oil, as described above. The contribution from the oil loading was insignificant.

TABLE B-34. RESULTS OF SSMS, ICPES, AND AAS ELEMENTAL ANALYSIS OF COMBINED PRODUCT GAS[1]

	SSMS	ICPES	AAS		SSMS	ICPES	AAS
Aluminum	270	5300		Neodymium	0.39		
Antimony	0.78		12	Nickel	0.59	120	
Arsenic	32		16	Niobium	2		
Barium	>195	62		Osmium	ND		
Beryllium	0.16			Palladium	ND		
Bismuth	0.78			Phosphorus	>270		
Boron	200	180		Platinum	ND		
Bromine	42			Potassium	>3100	530	
Cadmium	0.59			Praseodymium	0.98		
Calcium	>770	2300		Rhenium	ND		
Cerium	5.5			Rhodium	ND		
Cesium	0.14			Rubidium	≥2.2		
Chlorine	430			Ruthenium	ND		
Chromium	84	82		Samarium	0.78		
Cobalt	≤1.8	0.84		Scandium	0.20		
Copper	12	290		Selenium	5.3		<1.7
Dysprosium	0.78			Silicon	>190		
Erbium	0.16			Silver	≤0.39		
Europium	0.20			Sodium	>1100	1100	
Fluorine	>190			Strontium	150		
Gadolinium	0.39			Sulfur**	>190		
Gallium	55			Tantalum	ND		
Germanium	3.7			Tellurium	0.20		
Gold	ND			Terbium	0.16		
Hafnium	≤0.39			Thallium	2.3		
Holmium	0.20			Thorium	1.6		
Iodine	0.78			Thulium	ND		
Iridium	ND			Tin	15		
Iron	>200	2700		Titanium	>190	150	
Lanthanum	3.9			Tungsten	0.78		
Lead	170			Uranium	1.4		
Lithium	45			Vanadium	>6.3	4.7	
Lutetium	ND			Ytterbium	ND		
Magnesium	>430	470		Yttrium	3.1		
Manganese	27	18		Zinc	300	170	
Mercury*	NR		2.4	Zirconium	15		
Molybdenum	1.8	6.4					

[1]Concentration in $\mu g/Nm^3$; includes impinger solutions, particulate and oil loadings.

*Value determined by gold amalgamation method is 4.6 $\mu g/Nm^3$.

**Value determined by FPD/GC is 1.1E6 $\mu g/Nm^3$.

ND - not detected.

NR - no record.

TABLE B-35. RESULTS OF SSMS, ICPES, AND AAS ELEMENTAL ANALYSIS OF COMBUSTION EMISSIONS FROM THE PRODUCT GAS BOILERS[1]

Element	Impingers	XAD-2 Resin	Particulates
Aluminum	570[2]	1.5	1000[2]
Antimony	<0.15[3]	ND	0.74[3]
Arsenic	<0.15[3]	BC	1.2[3]
Barium	<0.08[2]	128	12[2]
Beryllium	ND	ND	0.03
Bismuth	ND	ND	0.16
Boron	BC[2]	0.60	3.8[2]
Bromine	7.5	35	0.27
Cadmium	0.30	ND	0.12
Calcium	BC[2]	>700	470[2]
Cerium	ND	ND	1.1
Cesium	ND	ND	0.03
Chlorine	BC	BC	3.4
Chromium	2.3[2]	BC	0.78[2]
Cobalt	BC[2]	≤0.15	0.17[2]
Copper	BC[2]	>750	0.86[2]
Dysprosium	ND	ND	0.16
Erbium	ND	ND	0.03
Europium	ND	ND	0.04
Fluorine	BC	22	>39
Gadolinium	ND	ND	0.08
Gallium	≥0.38	0.08	11
Germanium	ND	ND	0.74
Gold	ND	ND	ND
Hafnium	ND	ND	≤0.08
Holmium	ND	ND	0.04
Iodine	0.08	<0.08	0.16
Iridium	ND	ND	ND
Iron	21[2]	6	470
Lanthanum	ND	ND	0.78
Lead	BC	ND	34
Lithium	≤0.08	0.53	1.1
Lutetium	ND	ND	ND
Magnesium	BC[2]	BC	94[2]
Manganese	0.53[2]	0.23	1.9[2]
Mercury	9.7[3]	NR	NR
Molybdenum	1.9[2]	0.38	0.30[2]

(Continued)

TABLE B-35. (Continued)

Element	Impingers	XAD-2 Resin	Particulates
Neodymium	ND	ND	0.08
Nickel	2.6[2]	1.4	0.62[2]
Niobium	ND	≤0.23	0.39
Osmium	ND	ND	ND
Palladium	ND	ND	ND
Phosphorus	BC	1.5	>39
Platinum	ND	ND	ND
Potassium	75[2]	BC	100[2]
Praseodymium	ND	ND	0.20
Rhenium	ND	ND	ND
Rhodium	ND	ND	ND
Rubidium	ND	0.15	0.35
Ruthenium	ND	ND	ND
Samarium	ND	ND	0.16
Scandium	≤0.15	≤0.15	0.04
Selenium	0.23[3]	ND	0.10[3]
Silicon	BC	BC	>39
Silver	BC	ND	≤0.08
Sodium	6[2]	<75	27[2]
Strontium	0.08	5.6	30
Sulfur**	BC	BC	>39
Tantalum	ND	ND	ND
Tellurium	ND	ND	0.04
Terbium	ND	ND	0.03
Thallium	ND	ND	0.47
Thorium	ND	ND	0.31
Thulium	ND	ND	ND
Tin	ND	ND	3
Titanium	0.76[2]	BC	30[2]
Tungsten	ND	ND	0.16
Uranium	ND	ND	0.27
Vanadium	BC[2]	0.45	0.94[2]
Ytterbium	ND	ND	ND
Yttrium	ND	≤0.15	0.62
Zinc	2.6[2]	BC	24[2]
Zirconium	BC	0.23	2.1

NR - No record.
BC - Value corrected for blank.
ND - Not detected.
[1]All concentrations in $\mu g/Nm^3$.
[2]Analyses performed by ICPES.
[3]Analyses performed by AAS.

*19.4 $\mu g/Nm^3$ by gold amalgamation method.
**3.25E5 $\mu g/Nm^3$ by EPA Method 6.
Note: Analysis performed by SSMS except where indicated.

TABLE B-36. RESULTS OF SSMS, ICPES, AND AAS ELEMENTAL ANALYSIS OF COMBUSTION EMISSIONS OF ESP OIL[1]

Element	Impingers	XAD-2 Resin	Particulates
Aluminum	600[2]	1.4	1200[2]
Antimony	<0.17[3]	ND	0.91[3]
Arsenic	<0.17[3]	BC	1.5[3]
Barium	<0.08[2]	BC	15[2]
Beryllium	ND	ND	0.04
Bismuth	ND	ND	0.19
Boron	85[2]	0.07	4.7[2]
Bromine	BC	0.68	0.34
Cadmium	ND	ND	0.15
Calcium	BC[2]	BC	570[2]
Cerium	ND	ND	1.3
Cesium	ND	ND	0.03
Chlorine	BC	BC	4.1
Chromium	390[2]	BC	1.1[2]
Cobalt	6.1[2]	≤0.07	0.21[3]
Copper	1.8[2]	BC	1.1[2]
Dysprosium	ND	ND	0.19
Erbium	ND	ND	0.04
Europium	ND	ND	0.05
Fluorine	BC	13	>48
Gadolinium	ND	ND	0.09
Gallium	<0.09	BC	13
Germanium	ND	ND	0.91
Gold	ND	ND	ND
Hafnium	ND	ND	≤0.09
Holmium	ND	ND	0.05
Iodine	BC	ND	0.19
Iridium	ND	ND	ND
Iron	1800[2]	BC	570[2]
Lanthanum	ND	ND	0.96
Lead	BC	0.14	42
Lithium	0.17	BC	1.3
Lutetium	ND	ND	ND
Magnesium	BC[2]	BC	110[2]
Manganese	37[2]	≤0.07	2.3[2]
Mercury*	0.19[3]	NR	0.04[3]
Molybdenum	28[2]	BC	0.37[2]

(Continued)

TABLE B-36. (Continued)

Element	Impingers	XAD-2 Resin	Particulates
Neodymium	ND	ND	0.09
Nickel	260[2]	BC	0.77[2]
Niobium	ND	ND	0.48
Osmium	ND	ND	ND
Palladium	ND	ND	ND
Phosphorus	BC	0.68	>48
Platinum	ND	ND	ND
Potassium	200[2]	BC	130[2]
Praseodymium	ND	ND	0.24
Rhenium	ND	ND	ND
Rhodium	ND	ND	ND
Rubidium	ND	ND	0.43
Ruthenium	ND	ND	ND
Samarium	ND	ND	0.19
Scandium	BC	<0.07	0.05
Selenium	<0.26[3]	BC	0.12[3]
Silicon	BC	BC	>48
Silver	BC	ND	<0.09
Sodium	38[2]	BC	33[2]
Strontium	BC	BC	37
Sulfur**	BC	BC	>48
Tantalum	ND	ND	ND
Tellurium	ND	ND	0.05
Terbium	ND	ND	0.04
Thallium	ND	ND	0.57
Thorium	ND	ND	0.39
Thulium	ND	ND	ND
Tin	ND	ND	3.7
Titanium	BC[2]	2.7	38[2]
Tungsten	ND	ND	0.19
Uranium	ND	ND	0.34
Vanadium	0.85[2]	<0.07	1.2[2]
Ytterbium	ND	ND	ND
Yttrium	ND	ND	0.77
Zinc	5.3[2]	BC	30[2]
Zirconium	ND	0.68	2.6

NR - No record.
BC - Value corrected for blank.
ND - Not detected.
[1]All concentrations in $\mu g/Nm^3$.
[2]Analyses performed by ICPES.
[3]Analyses performed by AAS.

*19.4 $\mu g/Nm^3$ by gold amalgamation method.
**3.25E5 $\mu g/Nm^3$ by EPA Method 6.
Note: Analysis performed by SSMS except where indicated.

TABLE B-37. ASH PAN WATER PH AND CONDUCTIVITY ANALYTICAL RESULTS

Date	Time	pH	Conductivity mho/cm at 25°C
2/24/81	1100	12.16	5560
	1600	12.30	5050
	2020	12.36	5080
2/25/81	0200	12.37	5210
	0620	12.32	5610
2/26/81		12.41	5470
2/27/81	1115	12.39	5640
	1420	12.39	6020
	1735	12.39	6040
3/5/81	1250	12.38	6000
	1555	12.32	6320
	2100	12.42	6140

TABLE B-38. RESULTS OF WATER QUALITY ANALYSES OF ASH PAN WATER[1]

Parameters	2/24-1600 hrs, 2020 hrs 2/25-0200 hrs, 0620 hrs	2/27-1115 hrs, 1420 hrs, 1735 hrs	3/5-1250 hrs, 1555 hrs, 2100 hrs
Phosphate (P)	0.66[1]	1.3	1.3
Chloride	205	195	200
Fluoride	0.48	0.56	0.64
Sulfide (S)	43	64	18
Sulfite (SO_3)	143	5.4	94
Nitrate (N)	1.1	4.4	2.5
Cyanide	0.19	<0.02	<0.02
Thiocyanate	<4	<4	<4
Sulfate (SO_4)	56	56	61
Ammonia (N)	<0.5	0.78	<0.5
COD	81	114	105
BOD	2.8	<1	1.8
TOC	3.8	3.2	3.2
Total Suspended Solids	136	151	151
Total Dissolved Solids	1740	1680	1950
pH (pH units)	12.5	12.5	12.5
Conductivity (average μmho/cm) at 25°C	5240 ± 260	5900 ± 320	6150 ± 160
Phenol	<0.006	<0.006	<0.006

[1]Concentration in μg/mL except where noted.

TABLE B-39. ANALYTICAL RESULTS: GASEOUS NH_3

Description	Sample Volume SCF 60°F 1 atm.	Sample Volume Nm_3 25°C 1 atm.	1st Imp. mg NH_3	2nd Imp. mg NH_3	Total mg NH_3	ppm NH_3	$\mu g/Nm^3$ NH_3
Combined Gas Run No. 1 2/24/81, 2024-2036 hrs.	3.794	0.1110	98.6	2.05	100.6	1310	9.07E5
Combined Gas Run No. 2 2/25/81, 0513-0529 hrs.	4.403	0.1288	100.5	2.13	102.6	1150	7.97E5
Combined Gas Run No. 3 2/25/81, 0937-0952 hrs.	3.480	0.1018	86.6	2.20	88.8	1260	8.71E2
Product Gas Boilers Run No. 1 2/25/81, 0222-0312 hrs.	22.547	0.6594	<0.15	<0.13	<0.28	<0.6	<4.25E2
Product Gas Boilers Run No. 2 2/25/81, 0820-0910 hrs.	21.127	0.6179	<0.15	<0.12	<0.27	<0.6	<4.37E2
Cleaned Top Gas Run No. 1 2/27/81, 1055-1111 hrs.	3.610	0.1056	189.0	0.56	189.6	1590	1.80E6
Cleaned Top Gas Run No. 2 2/27/81, 1655-1737 hrs.	6.554	0.1917	319.3	1.38	320.7	2410	1.67E6
Cleaned Top Gas Run No. 3 2/27/81, 1655-2057 hrs.	3.069	0.0898	164.0	2.18	166.2	2670	1.85E6
Raw Top Gas Run No. 1 2/27/81, 1047-1057 hrs.	3.430	0.1033	175.8	1.32	177.1	2450	1.77E6
Raw Top Gas Run No. 2 2/27/81, 1405-1415 hrs.	2.395	0.0700	125.9	0.56	126.5	2600	1.81E6
Raw Top Gas Run No. 3 2/27/81, 1706-1726 hrs.	5.008	0.1465	217.2	1.23	218.4	2150	1.49E6
Boiler No. 3 ESP Oils Run No. 1 3/3/81	19.024	0.5564	0.62	<0.12	0.62	1.6	1.11E3
Boiler No. 3 ESP Oils Run No. 2 3/3/81	18.957	0.5544	0.19	<0.13	0.19	0.5	3.43E3
Cleaned Bottom Gas Run No. 1 3/5/81, 1437-1452 hrs.	5.728	0.1675	9.51	0.92	10.4	89.7	6.23E4
Cleaned Bottom Gas Run No. 2 3/5/81, 1923-1937 hrs.	3.814	0.1115	3.23	0.38	3.61	46.6	3.24E4
Cleaned Bottom Gas Run No. 3 3/6/81, 0103-0113 hrs.	4.002	0.1170	97.8	0.33	98.1	1210*	8.39E5
Raw Bottom Gas Run No. 1 3/5/81, 0103-0113 hrs.	3.525	0.1030	3.69	<0.12	3.69	51.5	3.58E4
Raw Bottom Gas Run No. 2 3/5/81, 2111-2128 hrs.	3.781	0.1106	2.29	0.22	2.51	32.7	3.58E4
Raw Bottom Gas Run No. 3 3/6/81, 0114-0129 hrs.	3.617	0.1058	47.3	<0.06	47.3	644*	4.47E5

*Data rejected due to process upset.
aEb = a x 10^b

TABLE B-40. ANALYTICAL RESULTS: GASEOUS HCN

Description	Sample Volume SCF 60°F 1 atm.	Sample Volume Nm^3 25°C 1 atm.	1st Imp. mg HCN[1]	2nd Imp. mg HCN[1]	Total mg HCN	ppm HCN	$\mu g/Nm^3$ HCN
Combined Gas Run No. 1 2/24/81, 2041-2055 hrs.	4.165	0.1218	24.2	0.40	24.6	183	2.02E5
Combined Gas Run No. 2 2/25/81, 0537-0551 hrs.	4.353	0.1273	33.5	0.25	33.8	240	2.65E5
Combined Gas Run No. 3 2/25/81, 0955-1010 hrs.	3.170	0.0927	22.4	0.16	22.6	221	2.43E5
Product Gas Boilers Run No. 1 2/25/81, 0323-0415 hrs.	24.192	0.7075	1.23	<0.40	1.23	1.6	1.74E3
Product Gas Boilers Run No. 2 2/25/81, 0618-0658 hrs.	18.389	0.5378	0.89	0.005	0.89	1.5	1.66E3
Cleaned Top Gas Run No. 1 2/27/81, 1015-1050 hrs.	4.104	0.1200	33.4	0.39	33.8	255	2.82E5
Cleaned Top Gas Run No. 2 2/27/81, 1617-1652 hrs.	3.958	0.1158	32.3	0.14	32.4	252	2.80E5
Cleaned Top Gas Run No. 3 2/27/81, 2028-2040 hrs.	3.373	0.0986	19.2	0.36	19.6	180	1.98E5
Raw Top Gas Run No. 1 2/27/81, 1033-1043 hrs.	3.938	0.1152	34.9	0.38	35.3	278	3.06E5
Raw Top Gas Run No. 2 2/27/81, 1348-1358 hrs.	2.720	0.0795	20.7	0.28	21.0	239	2.64E5
Raw Top Gas Run No. 3 2/27/81, 1348-1358 hrs.	3.784	0.1107	26.8	0.31	27.1	222	2.45E5
Boiler #3 ESP Oil Run No. 1 3/3/81, 0945-1047 hrs.	19.107	0.5588	0.93	1.42	2.35	3.8	4.21E3
Boiler #3 ESP Oil Run No. 2 3/3/81, 1626-1736 hrs.	17.968	0.5255	2.88	0.43	3.31	5.7	6.30E3
Cleaned Bottom Gas Run No. 1 3/5/81, 1417-1434 hrs.	4.550	0.1331	6.67	0.04	6.71	45.7	5.04E4
Cleaned Bottom Gas Run No. 2 3/5/81, 1905-1919 hrs.	3.976	0.1163	4.98	<0.37	4.98	38.8	4.28E4
Cleaned Bottom Gas Run No. 3 3/6/81, 0117-0127 hrs.	4.091	0.1196	2.25	<0.38	2.25	17.0*	1.88E4
Raw Bottom Gas Run No. 1 3/5/81, 1440-1504 hrs.	3.726	0.1090	5.07	0.03	5.10	42.4	4.68E4
Raw Bottom Gas Run No. 2 3/5/81, 2052-2106 hrs.	4.022	0.1176	4.90	0.05	4.95	38.2	4.21E4
Raw Bottom Gas Run No. 3 3/6/81, 0057-0111 hrs.	3.704	0.1083	4.46	0.02	4.48	37.5*	4.14E4

[1]Includes both CN- and SCN- analyses converted to HCN. Adjusted for CO_2 absorbed by impinger solutions.

*Data rejected due to process upset.

$aEb = a \times 10^b$

TABLE B-41. ANALYTICAL RESULTS: GASEOUS NO_x

Description	Sample Volume SCF 60°F 1 atm.	Sample Volume Nm^3 25°C 1 atm.	µg NO_2	ppm NO_x	g/Nm^3 NO_x
Product Gas Boilers 2/26/81, 0525 hrs.	0.0497	0.001454	932	341	6.41E5
Product Gas Boilers 2/26/81, 0525 hrs.	0.0500	0.001462	750	273	5.13E5
Product Gas Boilers 2/27/81, 1005 hrs.	0.0501	0.001465	571	207	3.90E5
Boiler No. 3 ESP Oils 3/3/81, 1522 hrs.	0.0509	0.001489	1120	400	7.52E5
Boiler No. 3 ESP Oils 3/3/81, 1522 hrs	0.0502	0.001468	1240	449	8.45E5
Boiler No. 3 ESP Oils 3/3/81, 1910 hrs.	0.0478	0.001398	1115	424	7.98E5
Boiler No. 3 ESP Oils 3/3/81, 1910 hrs.	0.0477	0.001395	1045	399	7.49E5
Boiler No. 3 Natural Gas 3/4/81, 1022 hrs.	0.0466	0.001363	277	108	2.03E5
Boiler No. 3 Natural Gas 3/4/81, 1022 hrs.	0.0442	0.001293	272	112	2.10E5
Boiler No. 3 Natural Gas 3/4/81, 1127 hrs.	0.0432	0.001263	264	111	2.09E5
Boiler No. 3 Natural Gas 3/4/81, 1127 hrs.	0.0443	0.001296	260	107	2.01E5

aEb = a x 10^b

TABLE B-42. ANALYTICAL RESULTS: GASEOUS SO_x

Description	Sample Volume SCF 60°F 1 atm.	Sample Volume Nm^3 25°C 1 atm.	1st Imp. mg SO_2	2nd Imp. mg SO_2	Total mg SO_2	ppm SO_2	$\mu g/Nm^3$ SO_2
Product Gas Boilers Run No. 1, 2/25/81 0422-0500 hrs	16.159	0.4726	336.5	8.07	344.6	279	7.29E5
Product Gas Boilers Run No. 2, 2/25/81 0723-0800 hrs. & 0915-0945 hrs.	26.181	0.7657	510.1	10.2	520.3	260	6.80E5
Boiler No. 3 ESP Oils No. 1, 3/3/81, 1209-1251 hrs.	15.253	0.4461	183.1	1.61	184.7	158	414E5
Boiler No. 3 ESP Oils No. 2, 3/3/81, 1458-1430 hrs.	11.711	0.3425	139.7	1.06	140.8	157	411E5
Boiler No. 3 ESP Oils No. 3, 3/3/81, 1601-1623 hrs.	9.314	0.2724	95.5	1.00	96.5	135	3.54E5
Boiler No. 3 ESP Oils No. 4, 3/3/81, 1739-1810 hrs.	5.683	0.1662	59.6	1.31	60.9	140	3.66E5
Boiler No. 3 Natural Gas Run No. 1, 3/4/81, 1115-1145 hrs.	12.945	0.3786	4.04	0.68	4.72	4.8	1.25E4
Boiler No. 3 Natural Gas Run No. 2, 3/4/81, 1148-1218 hrs.	11.637	0.3403	2.90	0.35	3.25	3.7	9.55E3
Boiler No. 3 Natural Gas Run No. 3, 3/4/81, 1233-1303 hrs.	10.005	0.2926	1.61	0.36	1.97	2.6	6.73E3

$aEb = a \times 10^b$

TABLE B-43. WATER CONTENT OF GASEOUS PROCESS AND EMISSION STREAMS

Stream	Date	Time	(%)
Combined Product Gas	2/24	2024-2036	10.0
	2/25	0513-0529	9.24
	2/25	0937-0952	9.50
	2/26-27	2327-0015	10.5
	2/27	0315-0355	10.0
	2/27	0550-0635	8.47
	2/27	2230-2235	8.22
	2/28	0035-0130	10.4
	2/28	0225-0335	10.4
Combustion Emissions from Product Gas Boilers	2/25	0222-0312	9.81
	2/25	0422-0500	9.87
	2/25	0723-0800/0915-0945	8.70
	2/25	0820-0910	8.82
	2/25	0057-0701	8.66
Cleaned Top Product Gas	2/27	1055-1111	19.7
	2/27	1116-1615	19.4
	2/27	1655-1737	18.5
	2/27	1802-2022	19.3
	2/27	2045-2057	19.0
Raw Top Product Gas	2/27	1047-1057	20.0
	2/27	1102-1332	19.6
	2/27	1405-1415	19.7
	2/27	1435-1635	22.8
	2/27	1706-1726	14.4
Cleaned Bottom Product Gas	3/5	1437-1452	3.20
	3/5	1456-1856	4.71
	3/5	1923-1937	4.5
	3/5-6	2004-0056	4.25
Raw Bottom Product Gas	3/5	1508-1532	4.52
	3/5	1534-2046	3.62
	3/5	2111-2128	4.22
	3/5-6	2137-0046	6.24
Combustion Emissions from Boiler No. 3 Firing ESP Oil	3/3	1049-1205	7.05
	3/3	1209-1251	7.12
	3/3	1430-1458	6.89
	3/3	1601-1623	6.98
Combustion Emissions from Boiler No. 3 Firing Natural Gas	3/4	1115-1145	14.4
	3/4	1148-1218	14.7
	3/4	1233-1303	16.0

TABLE B-44. RESULTS OF ANALYSES FOR MAJOR GASES IN GASEOUS PROCESS AND EMISSION STREAMS[1]

STREAM	DATE	TIME	COMPONENT						TOTAL
			CO_2	H_2	O_2+ Ar	N_2	CH_4	CO	
Combined Product Gas	2/24/81	1015	3.44	18.8	0.62	48.6	2.16	30.6	104
	2/24/81	1145	3.91	19.9	0.60	48.7	2.39	30.6	106
	2/24/81	1325	3.35	16.3	0.61	49.8	1.92	30.3	102
	2/24/81	2330	4.13	19.8	1.03	54.0	2.26	32.0	113
	2/25/81	0115	3.90	19.3	0.53	52.6	2.20	31.9	110
	2/25/81	0320	4.87	18.3	1.30	46.7	1.80	24.2	97.2
	2/25/81	0550	3.90	17.8	0.67	46.6	1.56	26.1	96.6
	2/26/81	0905	5.26	16.4	0.53	46.2	2.61	28.0	99.0
	2/26/81	1015	4.2	13.6	0.57	44.9	2.01	28.2	93.5
	2/26/81	2225	5.06	14.6	0.80	50.2	1.93	28.0	100
	2/27/81	0050	4.76	15.0	0.78	48.2	1.94	28.4	99.1
	2/27/81	0415	4.74	15.0	0.97	49.0	1.97	28.9	100
	2/27/81	2050	4.22	13.6	0.74	47.1	1.84	29.2	96.7
	2/27/81	2335	3.53	13.2	0.71	43.3	1.92	27.7	90.4
	2/28/81	0145	3.99	14.0	0.78	43.9	1.91	27.7	92.3
	2/28/81	0345	4.14	12.2	0.68	43.7	1.72	26.7	89.2
	2/28/81	0545	3.93	13.6	0.76	42.8	1.87	26.8	89.8
	3/5/81	1704	5.24	15.7	0.80	45.4	2.61	28.5	98.3
Combustion Emissions from Product Gas Boiler	2/24/81	1540	8.24	0.07	12.3	80.9	ND	ND	101
	2/24/81	2040	8.52	ND	11.8	80.3	ND	ND	101
Cleaned Top Product Gas	2/26/81	1155	3.89	16.7	1.26	45.0	3.71	28.0	98.6
	2/26/81	1410	4.32	17.8	0.62	43.7	4.05	28.6	99.1
	2/27/81	1003	4.18	15.0	0.67	41.0	3.08	26.6	90.5
	2/27/81	1725	3.51	12.9	0.72	45.8	2.66	28.5	94.1
Raw Top Product Gas	2/26/81	1755	3.67	15.7	0.71	44.2	3.69	27.8	95.8
	2/26/81	2120	4.40	18.2	0.72	45.7	3.88	29.8	103
	2/27/81	1328	3.44	15.3	0.70	42.8	3.16	28.4	93.8
	2/27/81	1500	3.46	15.3	0.89	41.1	3.76	27.7	92.2
Cleaned Bottom Product Gas	3/5/81	1338	4.63	12.2	0.79	54.0	0.39	31.8	104
	3/5/81	1521	5.63	11.5	0.80	54.5	ND	30.8	103
Raw Bottom Product Gas	3/5/81	2021	6.34	11.9	0.89	53.7	ND	30.8	104
	3/5/81	2252	5.89	9.08	0.84	48.8	ND	26.0	90.6
Combustion Emissions from Boiler No. 3 Firing ESP Oil	3/2/81	1135	9.74	ND	8.43	74.4	ND	ND	92.6
	3/2/81	1555	9.77	ND	9.81	75.6	ND	ND	95.2
	3/2/81	1825	10.1	ND	12.3	85.1	ND	ND	107
	3/3/81	0908	10.4	ND	8.38	74.8	ND	ND	93.6
	3/3/81	1150	10.9	ND	8.61	77.3	ND	ND	96.8
	3/3/81	1355	10.8	ND	8.72	77.3	ND	ND	96.9
Combustion Emissions for Boiler No. 3 Firing Natural Gas	3/4/81	1155	9.79	ND	4.87	83.5	ND	ND	98.2

[1]Concentration in volume percent

TABLE B-45. RESULTS OF ANALYSES FOR HYDROCARBONS IN GASEOUS PROCESS AND EMISSION STREAMS[1]

STREAM	DATE	TIME	COMPONENT						
			CH_4	C_2H_6	C_2H_4	C_3	C_4	C_5	C_6
Combined Product Gas	2/24/81	1015	1.92E4	1.58E3	2.68E2	8.02E2	3.65E2	2.36E2	2.46E2
	2/24/81	1145	9.50E3	7.63E3	1.28E2	3.92E2	1.82E2	1.16E2	1.19E2
	2/24/81	1325	1.71E4	1.40E3	2.37E2	7.10E2	3.22E2	2.10E2	2.30E2
	2/24/81	2325	1.92E4	1.60E3	2.65E2	8.12E2	3.71E2	2.40E2	3.16E2
	2/25/81	0115	1.80E4	1.49E3	2.48E2	7.56E2	3.45E2	2.21E2	2.72E2
	2/25/81	0320	2.00E4	1.62E3	2.72E2	8.25E2	3.75E2	2.44E2	3.23E2
	2/25/81	0540	1.62E4	1.25E3	2.06E2	6.35E2	2.88E2	1.87E2	2.58E2
	2/26/81	1015	1.57E4	1.20E3	2.18E2	6.46E2	2.88E2	1.74E2	2.07E2
	3/5/81	1712	2.41E4	1.84E3	3.92E2	9.48E	4.61E2	2.72E2	3.12E2
Combustion Emissions from Product Gas Boilers	2/24/81	1540	ND	ND	ND	ND	ND	ND	7.84E2
	2/24/81	2015	ND	ND	ND	ND	ND	ND	1.80E2
Cleaned Top Product Gas	2/26/81	1135	3.38E4	2.52E3	4.44E2	1.33E3	6.03E2	3.93E2	4.61E2
	2/26/81	1400	3.54E4	2.66E3	4.68E2	1.40E3	6.28E2	3.80E2	4.40E2
	2/27/81	0940	3.00E4	2.20E3	3.91E2	1.16E3	5.20E2	3.18E2	3.81E2
	2/27/81	1715	1.91E4	1.50E3	2.76E1	7.94E2	3.56E2	2.19E2	2.49E2
Raw Top Product Gas	2/26/81	1810	3.51E4	2.80E3	4.88E2	1.47E3	6.68E2	4.04E2	4.54E2
	2/26/81	2140	3.05E4	2.21E3	4.98E2	1.30E3	5.83E2	3.59E2	4.70E2
	2/27/81	1334	3.68E4	2.86E3	5.26E2	1.52E3	6.78E2	4.18E2	4.74E2
	2/27/81	1447	3.43E4	2.41E3	5.53E2	1.44E3	6.34E2	3.81E2	4.01E2
Cleaned Bottom Product Gas	3/5/81	1345	5.64E2	ND	1	ND	ND	ND	7
	3/5/81	1531	4.22E2	ND	ND	ND	ND	ND	ND
Raw Bottom Product Gas	3/5/81	2027	5.98E2	ND	ND	ND	ND	ND	ND
	3/5/81	2300	5.13E2	ND	ND	ND	ND	ND	ND
Combustion Emissions from Boiler No. 3 Firing ESP Oil	3/2/81	1150	ND	ND	ND	ND	ND	ND	ND
	3/2/81	1605	ND	ND	ND	ND	ND	ND	ND
	3/2/81	1833	ND	ND	ND	ND	ND	ND	ND
	3/3/81	0934	ND	ND	ND	ND	ND	ND	ND
	3/3/81	1158	ND	ND	ND	ND	ND	ND	ND
	3/3/81	1408	ND	ND	ND	ND	ND	ND	ND
	3/3/81	1806	ND	ND	ND	ND	ND	ND	ND
Combustion Emissions from Boiler No. 3 Firing Natural Gas	3/4/81	1205	ND	ND	ND	ND	ND	ND	ND

$aEb = a \times 10^b$

ND - Not detected (<0.1 ppm)

[1]Concentrations in parts per million (volume) - ppm

TABLE B-46. RESULTS OF ANALYSES FOR SULFUR SPECIES IN GASEOUS PROCESS AND EMISSIONS STREAMS[1]

STREAM	DATE	TIME	COMPONENT						
			H_2S	COS	SO_2	CH_3SH	C_2H_4SH	CS_2	C_4H_4S
Combined Product Gas	2/24/81	1015	794	77	ND	24	<1	<1	<1
	2/24/81	1145	867	74	ND	21	<1	<1	<1
	2/24/81	1325	746	78	ND	22	<1	<1	<1
	2/24/81	2325	663	70	ND	20	2	>1	ND
	2/25/81	0115	778	72	ND	21	2	<1	<1
	2/25/81	0230	726	72	ND	21	2	<1	<1
	2/25/81	0540	697	75	ND	16	2	<1	ND
	2/26/81	1015	713	75	ND	20	2	<1	ND
	3/5/81	1712	856	79	ND	38	4	<1	<1
	3/5/81	1329	612	86	ND	21	2	<1	ND
Combustion Emissions from Product Gas Boilers	2/24/81	1540	ND	ND	240	ND	ND	ND	ND
	2/24/81	2015	ND	ND	231	ND	ND	ND	ND
Cleaned Top Product Gas	2/26/81	1135	757	57	ND	37	3	<1	1
	2/26/81	1400	781	57	ND	38	3	<1	ND
	2/27/81	0940	695	55	ND	40	3	ND	1
	2/27/81	1715	708	57	ND	42	ND	ND	ND
Raw Top Product Gas	2/26/81	1810	774	58	ND	41	4	<1	1
	2/27/81	1334	715	56	ND	40	4	<1	1
	2/27/81	1447	751	56	ND	40	4	ND	
Combustion Emissions from Boiler No. 3 Firing ESP Oil	3/2/81	1150	ND	5	*	ND	ND	ND	ND
	3/2/81	1605	ND	<1	77	ND	ND	ND	ND
	3/2/81	1833	ND	ND	160	ND	ND	ND	ND
	3/3/81	0904	ND	ND	220	ND	ND	ND	ND
	3/3/81	1158	ND	ND	219	ND	ND	ND	ND
	3/3/81	1408	ND	ND	245	ND	ND	ND	ND
	3/3/81	1808	ND	ND	206	ND	ND	ND	ND
Combustion Emissions from Boiler No. 3 Firing Natural Gas	3/4/81	1205	ND	ND	DR	ND	ND	ND	ND
Cleaned Bottom Product Gas	3/5/81	1345	84	322	ND	ND	ND	<1	ND
	3/5/81	1531	92	313	ND	ND	ND	ND	ND
Raw Bottom Product Gas	3/5/81	2027	809	92	ND	ND	ND	<1	ND
	3/5/81	2300	860	104	ND	ND	ND	<1	ND

*Results not reproducible.
<1 = Quantifiable detection limit.
ND = Not detected (<0.1 ppm).
[1]Concentrations in parts per million (volume) - ppm.
DR = Data rejected due to analytical error.

TABLE B-47. RESULTS OF ANALYSES FOR ORGANIC LOADING

STREAM	TCO CONCENTRATION	GRAV CONCENTRATION	ORGANIC LOADING
Combustion Emissions from Product Gas Boilers	2.7 E1 $\mu g/Nm^3$	BC	2.7 E1 $\mu g/Nm^3$
Combustion Emissions from Boiler No. 3 Firing ESP Oil	5.8 E2 $\mu g/Nm^3$	2.1 E3 $\mu g/Nm^3$	2.7 E3 $\mu g/Nm^3$
Combined Product Gas	3.7 E6 $\mu g/Nm^3$	3.1 E5 $\mu g/Nm^3$	4.0 E6 $\mu g/Nm^3$
Aerosols	1.2 E5 $\mu g/Nm^3$	9.0 E4 $\mu g/Nm^3$	2.1 E5 $\mu g/Nm^3$
Vapors	3.6 E6 $\mu g/Nm^3$	2.2 E5 $\mu g/Nm^3$	3.8 E6 $\mu g/Nm^3$
Cleaned Top Product Gas	6.9 E6 $\mu g/Nm^3$	4.8 E5 $\mu g/Nm^3$	7.4 E6 $\mu g/Nm^3$
Aerosols	1.2 E5 $\mu g/Nm^3$	2.2 E4 $\mu g/Nm^3$	1.5 E5 $\mu g/Nm^3$
Vapors	6.8 E6 $\mu g/Nm^3$	4.6 E5 $\mu g/Nm^3$	7.2 E6 $\mu g/Nm^3$
Raw Top Product Gas	8.8 E6 $\mu g/Nm^3$	3.8 E6 $\mu g/Nm^3$	1.3 E7 $\mu g/Nm^3$
Aerosols	3.6 E6 $\mu g/Nm^3$	3.8 E6 $\mu g/Nm^3$	7.4 E6 $\mu g/Nm^3$
Vapors	5.2 E6 $\mu g/Nm^3$	6.0 E3 $\mu g/Nm^3$	5.2 E6 $\mu g/Nm^3$
Cleaned Bottom Product Gas	8.8 E4 $\mu g/Nm^3$	7.1 E2 $\mu g/Nm^3$	8.9 E4 $\mu g/Nm^3$
Raw Bottom Product Gas	1.0 E4 $\mu g/Nm^3$	1.5 E3 $\mu g/Nm^3$	1.2 E4 $\mu g/Nm^3$
Gasifier Ash	7.3 E1 $\mu g/g$	3.0 E1 $\mu g/g$	1.0 E2 $\mu g/g$
Cyclone Dust	BC	1.2 E2 $\mu g/g$	1.2 E2 $\mu g/g$
ESP Oils	8.6 E4 $\mu g/g$	8.4 E5 $\mu g/g$	9.3 E5 $\mu g/g$
Ash Pan Water	1.0 E3 $\mu g/L$	BC	1.0 E3 $\mu g/L$

BC - Value equal to or less than blank.
$aEb = a \times 10^b$

TABLE B-48. RESULTS OF GC-HECD ANALYSIS FOR ORGANIC SULFUR*

STREAM	TOTAL ORGANIC SULFUR	MAJOR PEAK**
Combustion Emissions from Product Gas Boilers	4.44 E1 μg /Nm^3	1.29 E1 μg/Nm^3
Combustion Emissions from Boiler No. 3 Firing ESP Oil	3.30 E1 μg/Nm^3	5.43 E0 μg/Nm^3
Combined Product Gas	4.16 E4 μg/Nm^3	2.92 E3 μg/Nm^3
Gasifier Ash	3.42 E0 μg/g	3.32 E0 μg/g
Cyclone Dust	1.75 E1 μg/g	1.72 E1 μg/g
ESP Oils	5.63 E3 μg/g	3.06 E2 μg/g
Ash Pan Water	9.21 E2 μg/L	8.99 E2 μg/L

*Analysis performed by gas chromatograph with Hall electrolytic conductivity detector (HECD) in sulfur-specific mode.

**Quantitation of single major peak of chromatogram - indicates maximum concentration of a single sulfur-containing compound.

$aEb = a \times 10^b$

TABLE B-49. RESULTS OF GC-HECD ANALYSIS FOR ORGANIC NITROGEN*

STREAM	TOTAL ORGANIC NITROGEN	MAJOR PEAK**
Combustion Emissions from Product Gas Boilers	1.74 E0 $\mu g/Nm^3$	1.09 E0 $\mu g/Nm^3$†
Combustion Emissions from Boiler No. 3 Firing ESP Oil	3.91 E0 $\mu g/Nm^3$	3.67 E0 $\mu g/Nm^3$
Combined Product Gas	2.44 E4 $\mu g/Nm^3$	8.76 E3 $\mu g/Nm^3$
Gasifier Ash	BC	2.82 E4 $\mu g/g$†
Cyclone Dust	BC	BC
ESP Oils	6.58 E2 $\mu g/g$	7.09 E1 $\mu g/g$
Ash Pan Water	3.12 E-1 $\mu g/L$	2.46 E-1 $\mu g/L$

*Analysis of extract of XAD-2 resin or liquid or solid sample performed by gas chromatograph with Hall electrolytic conductivity detector (HECD) in nitrogen-specific mode.

**Quantitation of single major peak of chromatogram - indicates maximum concentration of a single nitrogen-containing organic compound.

BC - Value equal to or less than blank.

†No corresponding peak in blank, therefore, measured sample concentration not reduced by blank value.

$aEb = a \times 10^b$

TABLE B-50. RESULTS OF GC-HECD ANALYSIS FOR ORGANIC HALOGEN*

STREAM	TOTAL ORGANIC HALOGEN	MAJOR PEAK**
Combustion Emissions from Product Gas Boilers	BC	BC
Combustion Emissions from Boiler No. 3 Firing ESP Oil	1.15 E0 $\mu g/Nm^3$	4.29 E-1 $\mu g/Nm^3$
Combined Product Gas	1.21 E2 $\mu g/Nm^3$	1.21 E2 $\mu g/Nm^3$
Gasifier Ash	1.85 E-2 $\mu g/g$	5.00 E-3 $\mu g/g$
Cyclone Dust	4.80 E-2 $\mu g/g$	4.80 E-2 $\mu g/g$
ESP Oils	BC	BC
Ash Pan Water	3.05 $\mu g/L$	3.05 $\mu g/L$

*Analysis performed by gas chromatograph with Hall electrolytic conductivity detector (HECD) in halogen-specific mode.

**Quantitation of single major peak of chromatogram - indicates maximum concentration of a single halogen-containing organic compound.

BC - Value equal to or less than blank.

TABLE B-51. RESULTS OF GC-ECD ANALYSIS FOR POLYCHLORINATED BIPHENYLS*

STREAM	CONCENTRATION[1]
Combustion Emissions from Product Gas Boilers	<3.4 $\mu g/Nm^3$
Combustion Emissions from Boiler No. 3 Firing ESP Oil	<2.4 $\mu g/Nm^3$
Combined Product Gas	<290 $\mu g/Nm^3$
Gasifier Ash	<0.4 $\mu g/g$
Cyclone Dust	<0.13 $\mu g/g$
ESP Oils	<200 $\mu g/g$
Ash Pan Water	<6.7 $\mu g/L$

*Analysis performed by gas chromatograph with electron capture detector (ECD)
[1]All results below analytical detection limit.

TABLE B-52. RESULTS OF GC/MS ANALYSIS OF GASIFIER ASH[1]

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. μg/g
1	8.10	NI[2]	69208	0.76	0.151
2	8.15	NI	113851	1.25	0.249
3	8.23	NI	71800	0.79	0.157
4	8.33	NI	39129	0.43	0.086
5	8.43	Alkyl benzene	254590	2.79	0.555
6	8.63	Alkyl benzene	735384	8.06	1.60
7	8.78	NI	50614	0.56	0.111
8	8.93	NI	24411	0.27	0.054
9	9.05	Alkyl benzene	111243	1.22	0.243
10	9.10	m-Menthane	97060	1.06	0.211
11	9.17	NI	49080	0.54	0.107
12	9.27	NI	21180	0.23	0.048
13	9.37	Alkyl benzene	389617	4.27	0.850
14	9.55	C_{10}	482822	5.29	1.05
15	9.72	NI	17947	0.20	0.039
16	9.78	NI	22754	0.25	0.049
17	9.83	NI	34028	0.37	0.074
18	9.98	NI	12079	0.13	0.026
19	10.10	Hydrocarbon	284832	3.12	0.621
20	10.22	Cyclic hydrocarbon	172528	1.89	0.376
21	10.27	NI	93643	1.03	0.205
22	10.32	Alkane	24375	0.27	0.053
23	10.43	Alkane	85661	0.94	0.187
24	10.53	C_{11} alkene	6878	0.08	0.016
25	10.60	C_{11} alkene	13187	0.14	0.028
26	10.77	NI	127938	1.40	0.279
27	10.80	Alkyl benzene	22928	0.25	0.049
28	10.90	Alkane	128623	1.41	0.281
29	10.95	Alkyl benzene	69902	0.77	0.153
30	11.07	Alkane	107890	1.18	0.235
31	11.15	Alkyl benzene	19600	0.21	0.042
32	11.20	Alkane	75334	0.83	0.165
33	11.30	Unsaturated hydrocarbon	18372	0.20	0.039
34	11.33	NI	27860	0.31	0.062
35	11.40	Alkyl benzene	50838	0.56	0.111
36	11.43	Alkyl benzene	41206	0.45	0.089
37	11.55	NI	31445	0.34	0.067
38	11.60	Alkyl benzene	92815	1.02	0.203
39	11.87	NI	41120	0.45	0.089

(Continued)

TABLE B-52. (Continued)

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. μg/g
40	11.97	C_{11}	448586	4.92	0.979
41	12.08	Alkyl benzene	23879	0.26	0.052
42	12.18	NI	31121	0.34	0.067
43	12.35	Alkyl benzene	69104	0.76	0.151
44	12.45	Alkyl benzene	16665	0.18	0.036
45	12.60	Hydrocarbon	69349	0.76	0.151
46	12.80	Cyclic C_{11}	53321	0.58	0.115
47	12.90	Hydrocarbon	39496	0.43	0.086
48	13.08	Alkyl benzene	8534	0.09	0.016
49	13.25	NI	41488	0.45	0.089
50	13.32	NI	46870	0.51	0.101
51	13.52	Alkane	8879	0.10	0.019
52	13.65	Unsaturated hydrocarbon	34033	0.37	0.074
53	14.18	NI	18314	0.20	0.039
54	14.27	NI	33543	0.37	0.074
55	14.40	C_{12}	159974	1.75	0.348
56	14.72	Hydrocarbon	34916	0.38	0.076
57	15.33	NI	12365	0.14	0.028
58	15.80	NI	7485	0.08	0.016
59	16.03	NI	33255	0.36	0.072
60	16.67	NI	8401	0.09	0.018
61	16.78	C_{13}	336639	3.69	0.734
62	17.28	Aromatic cmpd.	31214	0.34	0.068
63	17.38	Aromatic cmpd.	12911	0.14	0.028
64	17.67	Hydrocarbon	19990	0.22	0.044
65	17.78	Aromatic cmpd.	43787	0.48	0.096
66	18.02	Aromatic cmpd.	17626	0.19	0.038
67	18.12	Alkyl benzene	32868	0.36	0.072
68	18.27	Alkyl benzene	86511	0.95	0.189
69	18.40	Alkyl benzene	89432	0.98	0.195
70	18.53	Hydrocarbon	41366	0.45	0.089
71	18.87	NI	8132	0.09	0.018
72	19.10	C_{14}	579057	6.35	1.26
73	19.48	Aromatic cmpd.	14788	0.16	0.032
74	19.88	Aromatic cmpd.	23382	0.26	0.052
75	20.03	NI	97118	1.06	0.211
76	20.15	Aromatic cmpd.	71747	0.79	0.157
77	20.30	Aromatic cmpd.	14274	0.16	0.032
78	20.40	Hydrocarbon	44160	0.48	0.096

(Continued)

TABLE B-52. (Continued)

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. μg/g
79	20.55	Aromatic cmpd.	128496	1.41	0.281
80	20.62	NI	57018	0.63	0.125
81	20.68	Aromatic cmpd.	146615	1.61	0.320
82	21.22	Hydrocarbon	183822	2.02	0.402
83	22.03	Aromatic cmpd.	101363	1.11	0.221
84	22.23	NI	62441	0.68	0.135
85	22.60	NI	39553	0.43	0.086
86	23.33	NI	558920	6.13	1.22
87	23.97	NI	22600	0.25	0.049
88	24.02	NI	59947	0.66	0.131
89	24.22	NI	49787	0.55	0.109
90	24.62	NI	38942	0.43	0.086
91	25.13	Unsaturated hydrocarbon	154920	1.70	0.338
92	25.23	NI	29285	0.32	0.064
93	25.33	NI	51747	0.68	0.135
94	25.83	NI	33212	0.36	0.072
95	25.93	NI	28146	0.31	0.062
96	26.15	NI	24558	0.27	0.054
97	26.55	NI	22725	0.25	0.049
98	26.97	d_{10} Anthracene	183750	2.01	--*
99	27.23	NI	23002	0.25	0.049
100	28.85	NI	13561	0.15	0.029
101	30.55	NI	13717	0.15	0.029
102	31.42	NI	73628	0.81	0.161
103	32.15	NI	14534	0.16	0.032
104	33.72	NI	14677	0.16	0.032
105	35.20	NI	15408	0.17	0.034
106	36.63	NI	17942	0.20	0.039
107	38.00	NI	17756	0.19	0.038
108	38.73	NI	29227	0.32	0.064
		Total Eluted		19.478 μg/g	
		Total Identified		14.003 μg/g	
		% Identified		71.9	

[1]Quantitated using the response factor for d_{10}-Anthracene because response factors for individual compounds were not available.
[2]NI - Not identified.
* - Internal reference standard.

TABLE B-53. RESULTS OF GC/MS ANALYSIS OF ASH PAN WATER[1]

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. μg/L
1	8.78	Phenol	9116	1.22	3.23
2	9.62	NI[2]	14147	1.89	5.00
3	9.93	NI	13077	1.75	4.63
4	10.12	NI	8904	1.19	3.15
5	10.58	Chlorinated Alkane	24940	3.33	8.82
6	10.75	NI	8758	1.17	3.10
7	11.87	Methyl benzoate	13181	1.76	4.66
8	12.63	Dichlorophenol	33742	4.51	11.9
9	13.12	NI	11595	1.55	4.10
10	13.75	NI	3102	0.41	1.09
11	14.18	NI	10021	1.34	3.55
12	14.53	NI	2924	0.39	1.03
13	14.73	NI	4860	0.65	1.72
14	15.13	NI	14053	1.88	5.00
15	15.35	NI	5720	0.76	2.01
16	17.10	NI	20615	2.75	7.28
17	17.18	NI	11974	1.60	4.24
18	18.28	NI	2925	0.39	1.03
19	20.63	Alkyl benzene	35364	4.73	12.5
20	21.25	NI	5769	0.77	2.04
21	21.60	NI	8061	1.08	2.86
22	23.30	NI	16617	2.22	5.88
23	25.15	Unsaturated hydrocarbon	125614	16.79	44.5
24	26.97	d_{10}-Anthracene	188453	25.18	--*
25	30.05	NI	2112	0.28	0.74
26	31.42	Sulfur	84359	11.27	29.8
27	32.40	NI	4992	0.67	1.77
28	33.73	NI	1924	0.26	0.69
29	36.70	Dioctyl adipate	33373	4.46	11.8
30	38.77	Bis(2-ethylhexyl) phthalate	22403	2.99	7.92
31	44.18	NI	5588	0.75	1.99
		Total Eluted		198.02 μg/L	
		Total Identified		135.1 μg/L	
		% Identified		68.2	

[1]Quantitated using the response factor for d_{10}-Anthracene because response factors for individual compounds were not available.
[2]NI - Not identified.
* - Internal reference standard.

TABLE B-54. RESULTS OF GC/MS ANALYSIS OF CYCLONE DUST[1]

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. μg/g
1	3.57	NI[2]	1082511	23.00	3.45
2	4.17	Chlorine cmpd.	77697	1.65	0.247
3	4.82	Toluene	142489	3.03	0.454
4	6.50	NI	17669	0.38	0.057
5	6.65	Xylene	87783	1.87	0.280
6	7.12	NI	32591	0.69	0.103
7	7.27	NI	26478	0.56	0.084
8	7.47	NI	25979	0.55	0.082
9	8.00	NI	21460	0.46	0.069
10	8.45	NI	19610	0.42	0.063
11	8.65	NI	17043	0.36	0.054
12	8.80	NI	10173	0.22	0.033
13	917	NI	10370	0.22	0.033
14	9.37	Alkyl benzene	48253	1.03	0.154
15	9.52	C_{10}	46861	1.00	0.150
16	10.07	NI	29634	0.63	0.094
17	10.35	5-Methyl-1,3-benzenediol	138956	2.95	0.442
18	11.88	NI	17168	0.36	0.054
19	11.95	NI	57019	1.21	0.181
20	14.07	Naphthalene	34928	0.74	0.111
21	14.42	NI	33650	0.72	0.108
22	16.80	Alkyl naphthalene	30262	0.64	0.096
23	19.08	Dialkyl naphthalene	35558	0.76	0.114
24	21.10	Dialkyl naphthalene	14521	0.31	0.046
25	21.25	NI	47388	1.01	0.151
26	21.77	NI	18700	0.40	0.06
27	23.30	NI	9680	0.21	0.031
28	24.27	NI	20203	0.43	0.064
29	24.95	NI	26502	0.56	0.084
30	25.17	NI	48893	1.04	0.156
31	25.23	NI	44214	0.94	0.141
32	25.35	NI	42654	0.91	0.136
33	26.98	d_{10}-Anthracene	416816	8.86	--*
34	27.10	NI	73509	1.56	0.234
35	28.87	NI	67260	1.43	0.234
36	30.50	NI	18897	0.40	0.06
37	30.57	NI	89504	1.90	0.285

(Continued)

* - Internal reference standard.

TABLE B-54. (Continued)

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. μg/g
38	30.67	NI	56978	1.21	0.181
39	31.40	NI	284568	6.05	0.907
40	31.53	NI	453228	9.63	1.44
41	32.15	C_{21}	83593	1.78	0.267
42	33.70	C_{22}	107835	2.29	0.343
43	35.18	C_{23}	115987	2.46	0.369
44	36.60	C_{24}	124497	2.65	0.397
45	37.98	C_{25}	161607	3.43	0.514
46	38.72	NI	41121	0.87	0.130
47	39.30	C_{26}	117062	2.49	0.373
48	40.58	C_{27}	89512	1.90	0.285
49	41.82	NI	52732	1.12	0.168
50	43.00	NI	15731	0.33	0.049
51	45.10	NI	18594	0.40	0.06
		Total Eluted		13.671 μg/g	
		Total Identified		4.600 μg/g	
		% Identified		33.6	

[1]Quantitated using the response factor for d_{10}-Anthracene because response factors for individual compounds were not available.
[2]NI - Not identified.

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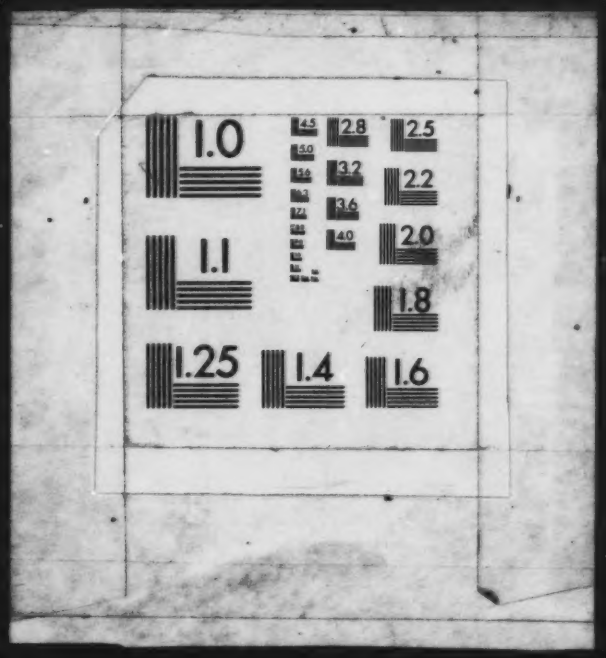


TABLE B-55. RESULTS OF GC/MS ANALYSIS OF COMBUSTION EMISSIONS FROM BOILER NO. 3 FIRING ESP OIL[1]

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. $\mu g/Nm^3$
1	8.30	Trichloropropane	93139	2.21	10.5
2	8.62	Benzaldehyde	33776	0.80	3.81
3	10.73	C_4-Alkyl benzene	29781	0.71	3.38
4	10.88	C_4-Alkyl benzene	18592	0.44	2.09
5	11.17	C_4-Alkyl benzene	29518	0.70	3.33
6	11.62	Methylindan	140864	3.34	15.9
7	11.80	Methylindan	44889	1.06	4.99
8	11.90	Methyl benzoate	63563	1.51	7.19
9	12.38	C_2 Alkyl styrene	27718	0.66	3.14
10	13.00	NI[2]	28785	0.68	3.24
11	13.57	Aliphatic aldehyde	50953	1.21	5.76
12	14.05	Naphthalene	259208	6.15	29.3
13	18.68	Biphenyl	34035	0.81	3.86
14	20.67	NI	63217	1.50	7.14
15	23.80	Alkyl biphenyl	32428	0.77	3.67
16	25.17	Unsaturated hydrocarbon	185984	4.41	26.0
17	26.87	Phenanthrene	26786	0.84	3.05
18	27.00	d_{10}-Anthracene	211249	5.01	--*
19	32.17	C_{21}	28684	0.68	3.24
20	33.72	C_{22}	78296	1.86	8.86
21	35.20	C_{23}	125733	2.98	14.2
22	36.77	Di-n-octyl adipate	2138340	50.70	241
23	38.00	C_{25}	129793	3.08	14.7
24	38.77	bis(2-ethylhexyl) phthalate	185477	4.40	20.9
25	39.33	C_{26}	103701	2.46	11.7
26	40.62	C_{27}	52845	1.25	5.95
		Total Eluted		451.9 $\mu g/Nm^3$	
		Total Identified		441.52 $\mu g/Nm^3$	
		% Identified		97.7	

[1]Quantitated using the response factor for d_{10}-Anthracene because response factors for individual compounds were not available.
[2]NI - Not identified.
* - Internal reference standard.

TABLE B-56. RESULTS OF GC/MS ANALYSIS OF COMBUSTION EMISSIONS FROM PRODUCT GAS BOILERS[1]

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. $\mu g/Nm^3$
1	8.62	Benzaldehyde	68494	4.88	8.43
2	9.52	Phenol	24319	1.73	2.99
3	10.75	NI[2]	17040	1.21	2.09
4	10.90	NI	15155	1.08	1.87
5	11.63	Ethyl styrene	98231	7.00	12.1
6	11.80	NI	35215	2.51	4.33
7	11.88	NI	30973	2.21	3.82
8	11.95	C_{11}	24251	1.73	2.99
9	12.38	Dimethylindan	43976	3.13	5.41
10	13.57	NI	18283	1.30	2.24
11	13.93	NI	17494	1.25	2.16
12	14.06	Naphthalene	175704	12.52	21.6
13	14.22	NI	14908	1.06	1.83
14	16.72	Methyl naphthalene	8458	0.60	1.04
15	17.12	NI	17231	1.23	2.12
16	18.70	NI	13358	0.95	1.64
17	19.08	NI	14010	1.00	1.73
18	20.65	Aromatic cmpd.	76994	5.49	9.48
19	21.25	NI	13018	0.93	1.61
20	23.33	Phthalate	39865	2.84	4.90
21	23.82	NI	23764	1.69	2.92
22	24.10	NI	17304	1.23	2.12
23	25.17	Unsaturated hydrocarbon	214802	15.30	26.4
24	26.88	Phenanthrene	17329	1.23	2.12
25	27.00	d_{10}-Anthracene	202785	14.45	—*
26	28.87	NI	12319	0.94	1.62
27	30.07	NI	14288	1.02	1.76
28	30.55	NI	13352	0.95	1.64
29	33.73	NI	10793	0.77	1.33
30	35.20	NI	12339	0.88	1.52
31	36.70	Di-n-octyl adipate	52601	3.75	6.48
32	38.78	Bis(2-ethylhexyl) phthalate	44078	3.14	5.42
		Total Eluted		147.71 $\mu g/Nm^3$	
		Total Identified		110.11 $\mu g/Nm^3$	
		% Identified		74.5	

[1]Quantitated using the response factor for d_{10}-Anthracene because response factors for individual compounds were not available.
[2]NI - Not identified.
* - Internal reference standard.

TABLE B-57. RESULTS OF GC/MS ANALYSIS OF COMBINED GAS[1]

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	$\mu g/Nm^3$
1	8.15	NI[2]	165018	0.30	1517
2	8.30	NI	90674	0.16	809
3	8.43	Alkyl benzene	296287	0.54	2731
4	8.65	Alkyl benzene	909703	1.65	8345
5	8.78	Alkyl benzene	452650	0.82	4147
6	9.07	Alkyl benzene	361148	0.65	3287
7	9.12	NI	172794	0.31	1568
8	9.42	Phenol	2037577	3.69	1.86E4
9	9.48	NI	219377	0.40	2023
10	9.58	Decane	462952	0.84	4248
11	9.70	Decalin	118769	0.22	1113
12	9.88	Decene	175244	0.32	1618
13	10.12	Alkyl benzene	1132667	2.05	1.04E4
14	10.42	Indan	572858	1.04	5259
15	10.62	NI	228986	0.41	2073
16	10.78	Alkyl benzene	308088	0.56	2832
17	10.92	NI	172427	0.31	1568
18	10.98	Cresol	913907	1.66	8395
19	11.07	Alkyl benzene	516850	0.94	4754
20	11.18	NI	10951	0.02	101
21	11.35	NI	72503	0.13	657
22	11.50	NI	475567	0.86	4349
23	11.67	Cresol	2221164	4.02	2.03E4
24	12.05	Undecane	802445	1.45	7333
25	12.13	Alkyl benzene	261255	0.47	2377
26	12.27	Xylenol	604261	1.09	5512
27	12.42	Aklyl benzene	232865	0.42	2124
28	12.55	Alkyl benzene	235041	0.43	2174
29	12.63	NI	57408	0.10	506
30	13.00	Methyl indan	361848	0.66	3337
31	13.12	NI	131048	0.24	1213
32	13.27	NI	372756	0.68	3438
33	13.33	Xylenol	1093977	1.98	1.00E4
34	13.40	NI	1007258	1.83	9254
35	13.57	NI	182954	0.33	1668
36	13.67	NI	36230	0.07	354
37	13.88	Xylenol	839028	1.52	7686
38	13.95	NI	911551	1.65	8344
39	14.08	Naphthalene	713885	1.29	6523
40	14.20	Alkyl indan	275182	0.50	2528

(Continued)

TABLE B-57. (Continued)

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. $\mu g/Nm^3$
41	14.27	Hydrocarbon	338158	0.61	3084
42	14.33	NI	266180	0.48	2427
43	14.47	Alkyl indan	1290487	2.34	11833
44	14.60	Dodecane	208829	0.38	1921
45	14.67	Alkyl phenol	191898	0.35	1769
46	14.72	NI	56429	0.10	505
47	14.82	Hydrocarbon	391759	0.71	3590
48	14.90	NI	431095	0.78	3944
49	15.03	NI	29071	0.05	252
50	15.23	NI	295402	0.54	2730
51	15.30	Alkyl phenol	1040255	1.88	9507
52	15.50	Alkyl phenol	461069	0.84	4247
53	15.58	Alkyl phenol	360382	0.65	3289
54	15.70	Methyl tetralin	149103	0.27	1365
55	15.80	Alkyl indan	156945	0.28	1415
56	15.96	Alkyl indan	443236	0.80	4045
57	16.05	Alkyl phenol	694707	1.26	6372
58	16.18	Alkyl phenol	687432	1.25	6321
59	16.28	Methyl tetralin	299511	0.54	2730
60	16.48	NI	780712	1.41	7130
61	16.60	NI	111193	0.20	1011
62	16.67	Tridecane	611824	1.11	5613
63	16.82	Methyl naphthalene	1375502	2.49	12591
64	16.90	NI	628947	1.12	5663
65	16.98	NI	440270	0.80	4045
66	17.20	Methyl naphthalene	1224050	2.22	11226
67	17.38	Aklyl tetralin	844627	1.53	7737
68	17.57	Alkyl tetralin	502046	0.91	4601
69	17.70	NI	78378	0.14	708
70	17.85	Alkyl tetralin	647123	1.17	5916
71	17.93	NI	179189	0.32	1618
72	18.05	NI	92505	0.17	859
73	18.28	Hydrocarbon	489814	0.89	4500
74	18.43	NI	469868	0.85	4298
75	18.60	Alkyl tetralin	598308	1.08	5461
76	18.73	NI	73046	0.13	657
77	18.95	NI	390169	0.71	3590
78	19.03	Hydrocarbon	418611	0.76	3843

(Continued)

TABLE B-57. (Continued)

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. $\mu g/Nm^3$
79	19.12	NI	109299	0.20	1011
80	19.23	Tetradecane	22765	0.04	202
81	19.33	NI	488075	0.88	4450
82	19.47	NI	156602	0.28	1416
83	19.67	Dimethyl naphthalene	659547	1.20	6068
84	19.75	Dimethyl naphthalene	1101908	2.00	10114
85	19.95	NI	197696	0.36	1820
86	20.07	Dimethyl naphthalene	297240	0.54	2730
87	20.15	Dimethyl naphthalene	193953	0.35	1769
88	20.27	NI	95497	0.17	859
89	20.33	NI	48186	0.09	455
90	20.40	Dimethyl naphthalene	151622	0.27	1365
91	20.48	Hydrocarbon	408844	0.74	3742
92	20.62	Alkyl benzene	198499	0.36	1820
93	20.73	Alkyl benzene	157545	0.29	1466
94	20.85	NI	106484	0.19	960
95	21.05	NI	674020	1.22	6169
96	21.12	NI	845886	1.53	7737
97	21.22	Alkyl phenol	18249	0.03	151
98	21.30	Pentadecane	759866	1.38	6978
99	21.40	NI	142832	0.26	1314
100	21.58	NI	127365	0.23	1163
101	21.70	Dibenzofuran	160869	0.29	1466
102	21.83	NI	561232	1.02	5158
103	21.90	Alkyl naphthalene	230068	0.42	2124
104	22.02	Alkyl naphthalene	218117	0.40	2023
105	22.17	NI	5021	0.01	50
106	22.35	Alkyl naphthalene	282842	0.51	2579
107	22.68	Alkyl naphthalene	1001691	1.82	9203
108	22.75	NI	340454	0.62	3135
109	23.08	Fluorene	208096	0.38	1921

(Continued)

TABLE B-57. (Continued)

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. $\mu g/Nm^3$
110	23.22	Alkyl naphthalene	1029048	1.86	9406
111	23.35	NI	663401	1.20	6068
112	23.42	NI	233755	0.42	2124
113	23.57	Alkyl naphthalene	203370	0.37	1871
114	23.83	Methyl fluorene	120337	0.22	1112
115	24.10	Methyl fluorene	89021	0.16	809
116	24.27	Hydrocarbon	428916	0.78	3944
117	24.80	Alkyl naphthalene	73661	0.13	657
118	24.95	Alkyl naphthalene	161954	0.29	1466
119	25.10	NI	417447	0.76	3843
120	25.27	Hydrocarbon	500967	0.91	4601
121	25.37	Hydrocarbon	468450	0.85	4298
122	25.70	NI	134934	0.24	1213
123	25.83	Hydrocarbon	364820	0.66	3337
124	26.03	NI	487280	0.88	4450
125	26.98	Anthracene	340075	0.62	3135
126	27.08	d_{10}-Anthracene	317469	0.58	--*
127	28.95	C_{19}	184001	0.33	1668
128	30.53	C_{20}	104509	0.19	960
129	30.65	NI	95905	0.17	859
130	32.17	C_{21}	74332	0.13	657
131	33.72	C_{22}	60380	0.11	556
132	35.18	C_{23}	62420	0.11	556
133	36.70	Di-n-octyl adipate	544497	0.99	5006
134	38.77	C_{25}	109951	0.20	1011
		Total Eluted			505875 $\mu g/Nm^3$
		Total Identified			369742 $\mu g/Nm^3$
		% Identified			73.1

[1]Quantitated using the response factor for d_{10}-Anthracene because response factors for individual compounds were not available.
[2]NI - Not identified.
* - Internal reference standard.

TABLE B-58. RESULTS OF GC/MS ANALYSIS OF ESP OIL TO BOILER NO. 3[1]

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. μg/g
1	11.40	Cresol	63002	0.28	270
2	11.93	Undecane	23291	0.10	96
3	13.20	Methyl cresol	7754	0.03	28.9
4	13.68	Methyl cresol	56833	0.25	241
5	14.03	Naphthalene	29696	0.13	125
6	14.40	C_{12}	52773	0.23	222
7	14.73	NI[2]	18863	0.08	77.0
8	15.88	NI	15603	0.07	67.4
9	16.42	Dimethyl indan	39007	0.17	164
10	16.58	NI	21255	0.09	86.7
11	16.68	1-Methylnaphthalene	124161	0.55	530
12	16.78	C_{13}	113731	0.51	491
13	17.10	2-Methylnaphthalene	91029	0.41	395
14	17.30	C_3-Alkyl indan	28787	0.13	125
15	17.48	C_3-Alkyl indan	34418	0.15	144
16	17.78	C_3-Alkyl indan	18673	0.08	77.0
17	18.27	NI	19028	0.08	77.0
18	18.55	NI	58735	0.26	250
19	18.88	NI	35631	0.16	154
20	18.97	Dimethylnaphthalene	56768	0.25	241
21	19.08	C_{14}	184670	0.82	790
22	19.23	Dimethylnaphthalene	118801	0.53	510
23	19.57	Dimethylnaphthalene	117813	0.52	500
24	19.63	NI	225335	1.00	963
25	20.00	Dimethylnaphthalene	41524	0.18	173
26	20.07	Dimethylnaphthalene	46440	0.21	202
27	20.35	Dimethylnaphthalene	59228	0.26	250
28	20.43	Alkane	109785	0.49	472
29	20.57	NI	45578	0.20	193
30	20.65	NI	109472	0.49	472
31	21.02	Dioctylethane	118077	0.53	510
32	21.08	Aromatic cmpd.	225243	1.00	963
33	21.17	Hydrocarbon	30601	0.14	135
34	21.25	NI	314695	1.40	1350
35	21.35	NI	23463	0.10	96.3
36	21.58	NI	9283	0.04	28.5
37	21.65	Dibenzofuran	30450	0.14	135
38	21.78	C_5-alkyl indan	169874	0.76	732
39	21.87	C_2 alkyl naphthalene	74812	0.33	318

(Continued)

TABLE B-58. (Continued)

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. µg/g
40	21.97	C_2-alkyl naphthalene	67596	0.30	289
41	22.17	C_5-alkyl indan	44986	0.20	193
42	22.30	C_3-alkyl naphthalene	39864	0.18	173
43	22.50	NI	32133	0.14	135
44	22.65	NI	396874	1.77	1700
45	22.72	C_3-alkyl naphthalene	67157	0.30	289
46	23.05	Fluorene	68222	0.30	289
47	23.18	C_3-alkyl naphthalene	562926	2.51	2420
48	23.30	C_{16}	405409	1.80	1730
49	23.42	Methyldibenzofuran	61960	0.28	270
50	23.57	NI	53628	0.24	231
51	23.83	Alkyl naphthalene	63148	0.28	270
52	24.10	NI	54526	0.24	231
53	24.27	Hydrocarbon	276958	1.23	1180
54	24.43	NI	70353	0.31	299
55	24.53	NI	24481	0.11	106
56	24.82	NI	66401	0.30	289
57	24.95	NI	46874	0.21	202
58	25.13	C_4-alkylnaphthalene	233160	1.04	1000
59	25.17	NI	159336	0.71	684
60	25.28	C_{17}	371567	1.65	1590
61	25.40	Alkane	476749	2.12	2040
62	25.50	C_4-alkylnaphthalene	34042	0.15	144
63	25.60	NI	38590	0.17	164
64	25.70	NI	108323	0.48	462
65	25.87	C_{19} Alkene	437571	1.95	1880
66	26.05	C_{11} Alkene	544403	2.42	2330
67	26.22	Alkyl naphthalene	37947	0.17	164
68	26.38	NI	7890	0.04	38.5
69	26.70	NI	19356	0.09	86.7
70	26.78	NI	22952	0.10	96.3
71	26.90	Phenanthrene	61327	0.28	270
72	27.00	d_{10}-Anthracene	458951	2.04	--*
73	27.13	C_{18}	571607	2.54	2450
74	27.20	NI	47006	0.21	202
75	27.28	NI	62759	0.28	270

(Continued)

* - Internal reference standard

TABLE B-58. (Continued)

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. µg/g
76	27.45	NI	27812	0.12	116
77	27.73	NI	52662	0.23	222
78	27.95	NI	42417	0.19	183
79	28.22	NI	38116	0.17	164
80	28.52	NI	9942	0.04	38.5
81	28.65	NI	13128	0.06	57.8
82	28.70	NI	52851	0.24	231
83	28.78	NI	161357	0.72	693
84	28.92	C_{19}	563125	2.51	2420
85	29.20	NI	87794	0.39	376
86	29.32	NI	34063	0.15	144
87	29.63	NI	16442	0.07	67.4
88	29.85	NI	29791	0.13	125
89	29.95	NI	16851	0.08	77.0
90	30.30	NI	44305	0.20	193
91	30.48	NI	114998	0.51	491
92	30.62	C_{20}	666847	2.95	2860
93	30.72	NI	280178	1.25	1200
94	30.88	NI	69692	0.31	299
95	31.22	NI	19951	0.09	86.7
96	31.42	NI	32051	0.14	135
97	31.52	NI	30717	0.14	135
98	31.92	NI	30436	0.14	135
99	32.12	NI	388955	1.73	1670
100	32.23	C_{21}	951449	4.24	4080
101	32.52	NI	54247	0.24	231
102	32.72	NI	10240	0.05	48.2
103	33.10	NI	13211	0.06	57.8
104	33.25	NI	26354	0.12	116
105	33.32	NI	20844	0.09	86.7
106	33.68	C_{22} alkene	335875	1.50	1440
107	33.80	n-C_{22}	1094215	4.87	4690
108	34.07	NI	61454	0.27	260
109	34.22	NI	32716	0.15	144
110	34.60	NI	29190	0.13	125
111	34.68	NI	8210	0.04	38.5
112	35.17	C_{23} alkene	328425	1.45	1410
113	35.28	C_{23}	1093270	4.87	4690
114	35.55	NI	81784	0.36	347
115	36.15	NI	21974	0.10	96.3
116	36.60	C_{24}-alkene	245626	1.09	1050

(Continued)

TABLE B-58. (Continued)

Peak Number	Retention Time	Identification	Peak Area	% Total Peak Area	Conc. µg/g
117	36.72	C_{24}	1168295	5.20	5010
118	36.98	NI	50825	0.23	222
119	37.52	NI	49764	0.22	212
120	38.10	C_{25}	1214471	5.41	5210
121	38.33	NI	47100	0.21	202
122	38.78	NI	5677	0.03	28.9
123	39.20	NI	52972	0.24	231
124	39.40	NI	1098823	4.89	4710
125	39.67	NI	19229	0.08	86.7
126	40.18	NI	15212	0.07	67.4
127	40.68	C_{27}	918497	4.09	3940
128	40.95	NI	31424	0.14	135
129	41.90	C_{28}	529158	2.36	2270
130	43.08	C_{29}	413215	1.84	1770
131	43.48	NI	11332	0.05	48.2
132	43.62	NI	49239	0.22	212
133	44.05	NI	33105	0.15	144
134	44.22	NI	145400	0.65	626
135	45.18	NI	83127	0.37	356
136	45.33	NI	75594	0.34	327
137	45.77	NI	83923	0.37	356
138	46.22	NI	39654	0.18	173
139	46.87	NI	29781	0.13	125
		Total Eluted		94324 µg/g	
		Total Identified		73361 µg/g	
		% Identified		77.8	

[1]Quantitated using the response factor for d_{10}-Anthracene because response factors for individual compounds were not available.
[2]NI - Not identified.

TABLE B-59. RESULTS OF LIQUID CHROMATOGRAPHY FRACTIONATION OF GASIFIER ASH

LC Fraction	TCO[1]	GRAV[1]
1	13	19
2	2.4	1.1
3	0.44	0
4	0	0
5	0	0
6	0.80	7.6
7	0	3.3
	17	31

	TCO (mg)	GRAV (mg)	Total (mg)
Total Sample[2]	15.0	7.0	22.0
Taken for LC[3]	11.8	5.5	17.3
Recovered[4]	3.1	5.7	8.8
% Recovered	26.3	103	50.9

[1]Concentration in μg/g.
[2]Quantity in sample prior to LC.
[3]Portion taken for LC.
[4]Quantity recovered from LC column.

TABLE B-60. RESULTS OF LIQUID CHROMATOGRAPHY FRACTIONATION OF COMBINED GAS CONDENSABLE ORGANICS

LC Fraction	TCO[1]	GRAV[1]
1	6.8E5	9.8E3
2	3.2E5	0
3	1.5E4	0
4	1.1E4	0
5	1.7E5	0
6	4.9E5	3.6E5
7	2.6E3	3.1E4
Total	1.7E6	4.0E5

	TCO (mg)	GRAV (mg)	Total (mg)
Total Sample[2]	4600	280	4880
Taken for LC[3]	92	5.6	97.6
Recovered[4]	43.4	10.2	53.6
% Recovered	47.1	182	54.9

[1]Concentration in $\mu g/Nm^3$.
[2]Quantity in sample prior to LC.
[3]Portion taken for LC.
[4]Quantity recovered from LC column.

TABLE B-61. RESULTS OF LIQUID CHROMATOGRAPHY FRACTIONATION OF ESP OILS TO BOILER NO. 3

LC Fraction	TCO[1]	GRAV[1]
1	2.0E4	3.1E4
2	6.3E3	6.7E4
3	3.9E3	9.0E4
4	0	0
5	0	7.9E3
6	2.4E3	1.6E5
7	0	0
TOTAL	3.2E4	6.4E5

	TCO (mg)	GRAV (mg)	Total (mg)
Total Sample[2]	21.9	214	552
Taken for LC[3]	4.4	42.8	47.2
Recovered[4]	1.6	32.6	34.2
% Recovered	37.3	76.1	72.5

[1]Concentration in μg/g.
[2]Quantity in sample prior to LC.
[3]Portion taken for LC.
[4]Quantity recovered from LC column.

TABLE B-62. RESULTS OF ANALYSES OF CHARCOAL TUBE EXTRACTS FOR BENZENE, TOLUENE, AND XYLENE[1]

Sample	Benzene	Toluene	Xylene
Combined Gas 1035-1045 300 sec	2.17E5	3.22E5	2.22E5
Combined Gas 1047-1052 150 sec	2.54E5	5.42E5	3.87E5
Cleaned Top Gas 1044-1059 450 sec	6.87E5	9.25E5	7.85E5
Cleaned Top Gas 1025-1030 1050 sec	5.03E3	9.71E5	8.93E5
Raw Top Gas 1616-1626 300 sec	4.95E5	7.40E5	4.80E5
Cleaned Bottom Gas 1758-1813 450 sec	5.28E3	5.08E4	9.83E3
Cleaned Bottom Gas 2319-2324 150 sec	ND	1.73E5	9.19E3
Raw Bottom Gas 0007-0022 450 sec	2.36E3	4.68E4	1.40E3
Product Gas Boilers 1447-1552 3200 sec (#2)	4.64E2	4.75E3	ND
Product Gas Boilers 1658-1708 500 sec (#2)	ND	3.69E4	ND
Boiler No. 3 Firing ESP Oils 1542-1722 2000 sec (#1)	8.39E2	8.08E3	ND
Boiler No. 3 Firing ESP Oils 1813-1823 500 sec (#2)	ND	4.25E4	ND

$aEb = a \times 10^b$

[1]Concentration in $\mu g/Nm^3$.

ND = Not detected.

APPENDIX C

SAMPLING TECHNIQUES

C.1.0 INTRODUCTION

This appendix describes the sampling techniques used to collect samples for the environmental assessment of the Foster Wheeler/Stoic two-stage gasifier on the University of Minnesota-Duluth (UMD) campus. Figure C-1 presents a simplified schematic of the gasification facility showing the sampling points. The streams sampled were:

Gaseous Streams:

- Combined product gas
- Raw top product gas (upstream from electrostatic precipitator)
- Cleaned product gas (downstream from electrostatic precipitator)
- Raw bottom product gas (upstream from cyclone)
- Cleaned bottom product gas (downstream from cyclone)
- Combustion emissions from product gas boilers
- Combustion emissions from Boiler No. 3 firing ESP oil
- Combustion emissions from Boiler No. 3 firing natural gas

Solid Streams:

- Coal
- Gasifier ash
- Cyclone dust

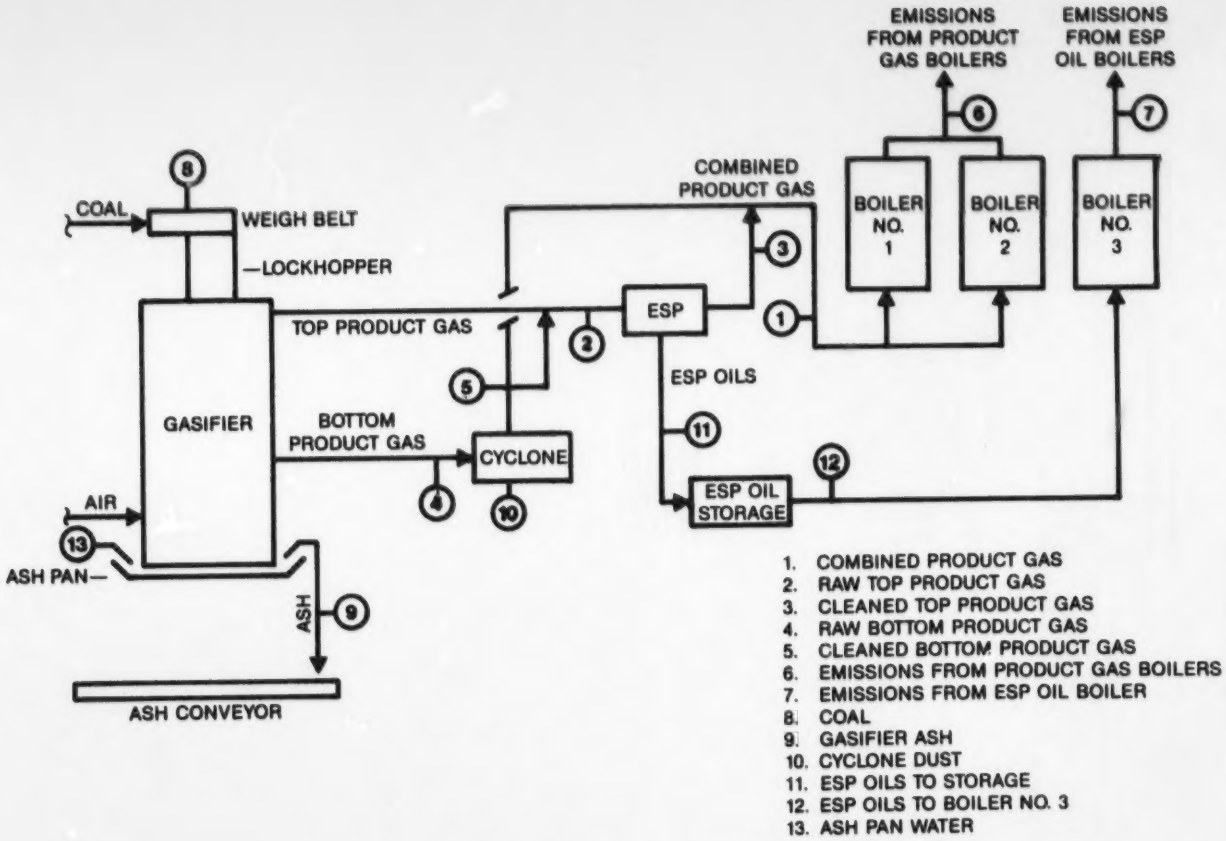


Figure C-1. The location of sampling points at the Foster Wheeler/Stoic two-stage gasifier at UMD.

Liquid Streams:

- ESP oil to storage
- ESP oil from storage to Boiler No. 3
- Ash pan water

The following sections describe the techniques used for sampling these streams.

C.2.0 PROCESS GASES

Five sampling points were used for the collection of process gas samples. The process streams sampled were the combined product gas, raw and treated top product gases, and raw and treated bottom product gases. These streams were sampled for the following parameters:

- aerosol and particulate,
- vapor phase organics,
- trace elements,
- ammonia,
- cyanide, and
- fixed gases, C_1-C_6 hydrocarbons, sulfur species, and benzene, toluene, and xylene (BTX).

Samples for all but the fixed gases, C_1-C_6 hydrocarbons, sulfur species, and BTX were taken isokinetically using a stainless steel probe fitted with the following:

- a packing gland system,
- a type S pitot,
- a type K thermocouple, and
- a gooseneck nozzle.

In all cases, because of sample port limitations, only a single traverse could be performed for flow calculations.

The sampling techniques for each of the above parameters are discussed in the following sections.

C.2.1 Aerosol and Particulate Collection

Because of the variety of process streams sampled, three different aerosol and particulate collection systems were used. These were:

- in-stream filtration using a glass fiber thimble (for the combined product gas and treated top gas),
- an electrostatic precipitator (ESP) followed by a glass fiber filter (for the raw top gas), and
- out-of-stream filtration using a glass fiber thimble in a heated oven (for the treated and raw bottom gases).

Samples recovered from the nozzle, probe, and collection device were weighed and used to calculate particulate loadings. The configurations of these collection systems are shown in Figure C-2 and discussed below.

C.2.1.1 Combined Product Gas and Cleaned Top Gas

The combined product gas and clean top gas streams contained cleaned gases at temperatures of 400°C (750°F), well above the dew point of the hydrocarbons of the process stream. They contained vaporized tars and oils as well as particulates. Because no aerosolized tars and oils were expected in the gas streams, and the process temperature did not exceed the limitations of the glass fiber material, the filtering system was placed on the in-stream portion of the probe. In-stream filtation was preferred for two reasons: 1) there was no need to provide external heat to the filter, and 2) no tars, oils, or particulates were deposited in the sample line prior to filtration. The aerosol and particulate collection system consisted of a

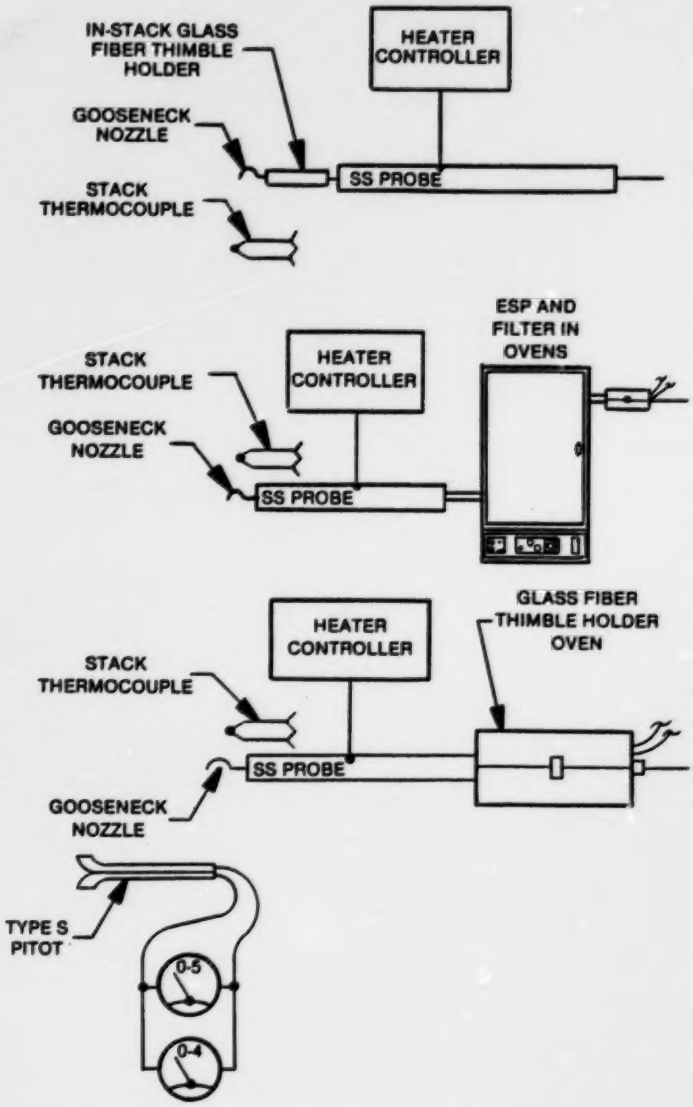


Figure C-2. Three sampling configurations for aerosol and particulate collection.

probe with a 30 x 100 mm glass fiber thimble and holder preceded by a gooseneck nozzle.

C.2.1.2 Raw Top Gas

The raw top gas stream contained a dispersion of aerosolized tars, oils, and particulate matter which had to be collected and assayed. An electrostatic precipitator was used to collect the aerosol from the raw top gas. The ESP was followed by a filter which captured any aerosol not collected by the ESP. The tar and oil loading and particulate loading were determined by combining the materials collected by the ESP and filter. The temperature of the top gas was approximately 95°C (200°F); this temperature did not present any significant problems to the sampling effort.

The collection system for the top gas consisted of:

- a probe with a gooseneck nozzle in-stream,
- an electrostatic precipitator in a heated oven, and
- a 43 x 123 mm pliable glass fiber thimble and holder in a heated oven.

The gas stream entered the lower portion of the ESP, shown in Figure C-3, and was directed toward a catch cup at the bottom of the ESP, thus permitting the collection of any easily removed material (particulate and organic aerosol) without fouling the upper portion of the ESP. As the gas stream moved upward through the ESP, electrostatic collection was induced by the 12 KV DC potential between the 0.025 mm center electrode and cylindrical shell. Colloidal sized aerosols were removed from the gas stream and forced to coalesce by their ultimate contact with the outer shell and other aerosol particles. Accumulated oils and tars flowed down the walls to the catch cup at the bottom of the ESP. The cleaned gas exited near the ESP top. Most collection occurred near the base of the ESP; the upper portions remained relatively free of material.

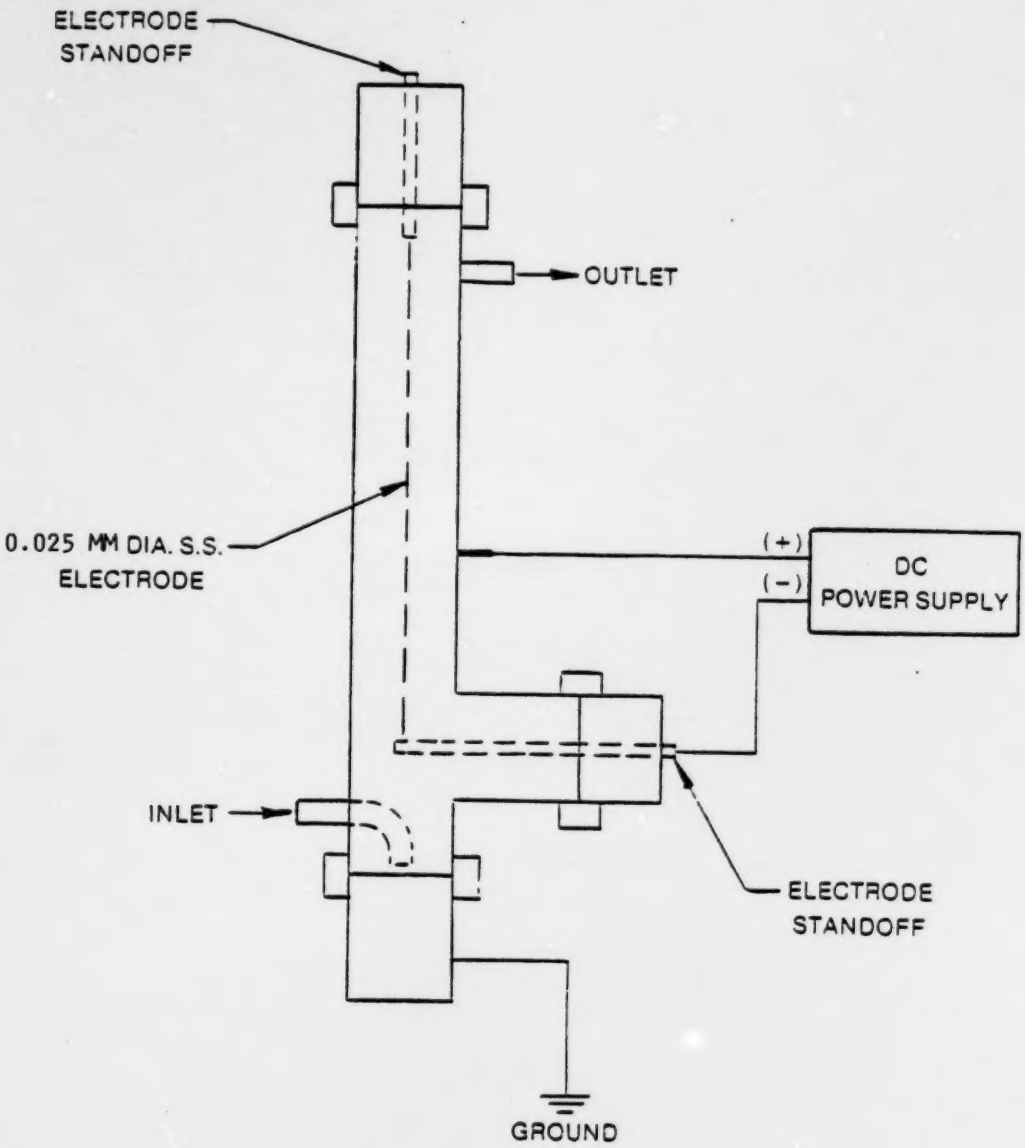


Figure C-3. A schematic of ESP used for aerosol and particulate removal.

ESPs of this configuration have been shown to be 99+% efficient for dry material of colloidal size. However, the primary reason for the use of the ESP was its ability to remove particulates and oil and tar aerosols without frequent stops for servicing or changing filtering elements. A glass fiber filter was used at the exit of the ESP as a polish and a back-up in the event of an ESP failure. The ESP temperature was held at 140°C (285°F) and the filter at 150°C (300°F) to avoid further condensation of any organic vapors remaining in the gas streams. Figure C-4 shows the ESP and filter in their respective ovens.

C.2.1.3 Bottom Gas

The bottom gas required a different sampling technique. No aerosolized tars and oils were expected in the bottom gas. Therefore, the ESP was not required. However, the temperature of the bottom gas, 650°C (1200°F), presented some problems in sampling.

Glass fiber filters have a temperature limitation of 480°C (900°F). For this reason, the filtering system could not be placed in the process stream. While it is desirable to have all parts of the probe and particulate sampling system at the temperature of the gas being sampled, the filter system, which was mounted on the outside end of the probe, could only be heated to 480°C. This was adequate since the condensable organics content of the bottom gas was low.

Both bottom gas sampling locations use the following system:

- a probe with a gooseneck nozzle, and
- a 43 x 123 mm pliable glass fiber filter and holder in a heated oven.

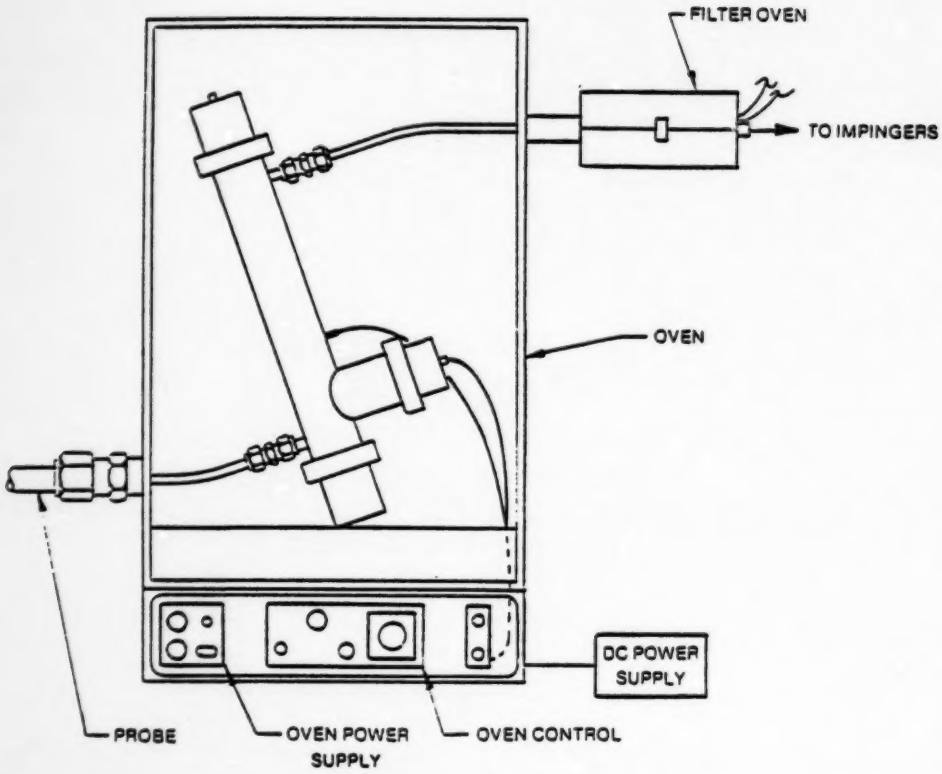


Figure C-4. ESP filter and assembly.

C.2.2 Organic Vapors

Organic vapors were collected using a sampling train having a condenser and XAD-2 resin cartridge for vapor collection. Figure C-5 shows the organic vapor sampling train used for the clean top gas and combined product gases. The sampling trains used for the other process gas streams were identical to the train shown in Figure C-5 with the exception of the aerosol and particulate collection devices (see Section 2.1).

Organic vapors were collectd by passing the gas stream through a condenser and an organic resin canister. The condenser served two purposes: it cooled the sample gas, and it collected condensed vaporous tars and oils from the sample gas stream. Uncondensed organic vapors were then adsorbed on the resin in the canister. Results of the analysis of condensed tars and oils and the uncondensed vapors (including probe rinse) were combined with the aerosol/particulate catch to give a total profile of the organic constituents in the process gas stream.

The condenser, constructed of stainless steel, is of triple chamber design. Cooling water circulates through a central cylindrical chamber, or core. This core is concentric with a surrounding chamber, through which the sample gas is passed. This chamber is likewise surrounded by a third concentric chamber which contains circulating cooling water.

The sample gas entered the condenser through a tangential inlet tube near the bottom and exited near the top. The cooling water (ice water) entered the condenser at the top and exited at the bottom. The countercurrent flow of the sample gas and cooling water assured a maximum temperature differential between the sample and coolant throughout the condenser. Tars and oils condensed from the sample gas stream were removed from the condenser through a drain port at the bottom of the gas circulation chamber.

Uncondensed organic vapors leaving the top of the condenser flowed to the resin canister. As the vapors entered the canister, they struck a

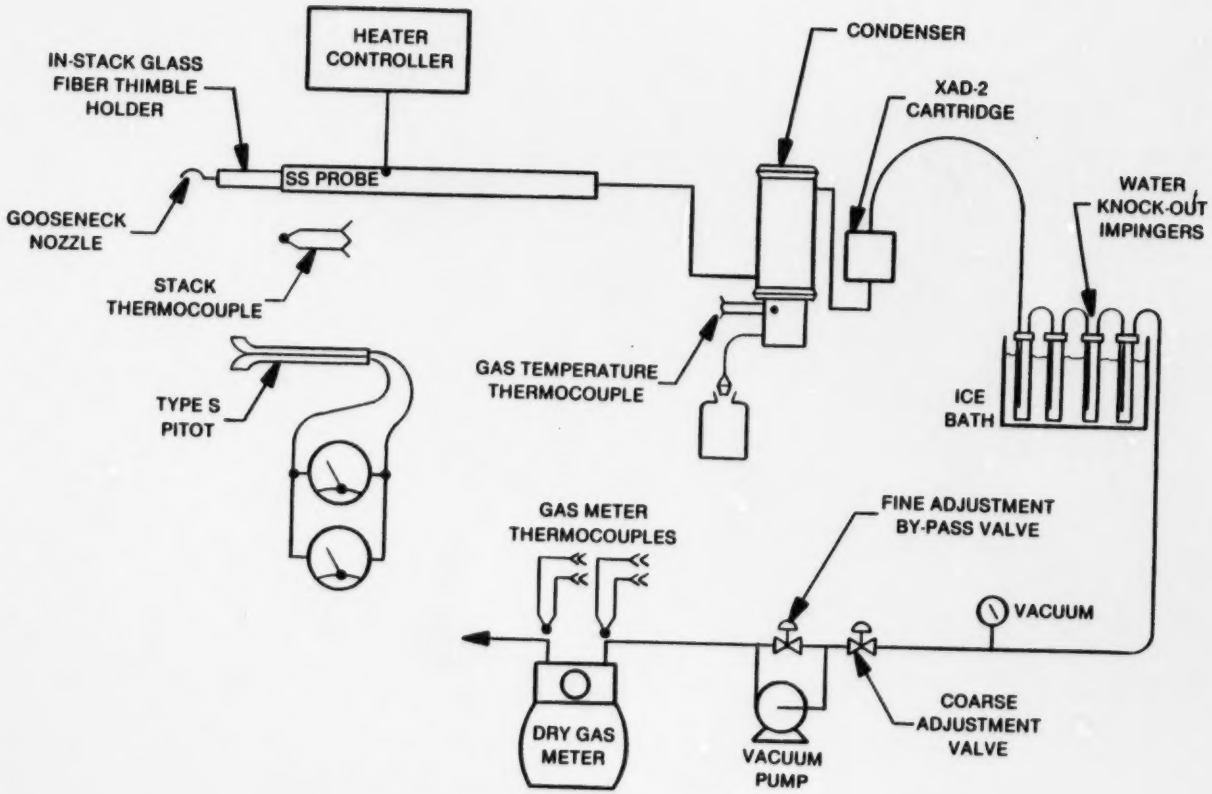


Figure C-5. Sampling system for organics -- cleaned top product gas and combined product gas.

perforated plate which is designed to distribute the gases evenly over the adsorption resin. The resin is held in the canister by discs of stainless steel wire mesh. Retaining rings are used to maintain the alignment of the distribution plates and wire mesh.

The pumping and metering devices used in the collection of organic vapors and in the collection of trace elements (as discussed in the following section) are contained in a commercially available console that has been modified. The two main components of the console are a double diaphragm pump and a dry gas meter. In addition, the console contains the following devices:

- an oil manometer and Magnehelic® gauge for measurement of pressure differential across the type S pitot,
- a digital temperature read-out with selector switch (for temperature measurement at several locations of the system),
- a Magnehelic® gauge for measurement of pressure drop across an orifice mounted behind the dry gas meter (a measurement of gas flow rate),
- heat controllers for the probe and filter hot box of the system, and
- two additional heat controllers.

C.2.3 Trace Elements, Ammonia and Cyanide

Gaseous inorganic components were collected by passing the sample gas stream through a series of Greenberg-Smith impingers which contained chemical solutions for removal of the species of interest from the gas stream. The species sought dictated the chemical solution or solutions to be used in the impinger and also the number of impingers. The final impinger contained a desiccant to remove moisture (which could have damaged the pumping and metering system) from the gas stream to provide dry gas for metering. During sampling, the impingers were housed in a cold box containing ice water.

This maintained the chemical solutions at a low temperature and increased the collection efficiency of the solutions. An example of the inorganic sampling train used for the bottom product gases is shown in Figure C-6. The sampling trains used for the other process gas streams were identical to the train shown in Figure C-6 with the exception of the aerosol and particulate collection devices (see Section 2.1).

C.2.3.1 Trace Elements

The impinger contents used for vapor phase trace element collection were:

1.	0.2M $(NH_4)_2S_2O_8$ + 0.2M $AgNO_3$	250 mL
2.	0.2M $(NH_4)_2S_2O_8$ + 0.2M $AgNO_3$	250 mL
3.	Dry	
4.	Preweighed silica gel	

The mass of aqueous condensate collected by the train plus the total volume of gas sampled were used to calculate moisture fractions for process gas streams.

Mercury is not collected efficiently in most liquid sorption systems. For more precise quantitation of vaporous mercury in a gas stream, a sample of the gas is passed over pure gold wire formed into a plug and placed in an enclosed glass tube. The mercury sampling tube is shown in Figure C-7. Sample volume is determined from time and flow rate measurements.

C.2.3.2 Ammonia

The impinger contents used for vapor phase ammonia collection were:

1.	5% H_2SO_4	100 mL
2.	5% H_2SO_4	100 mL
3.	Dry	
4.	Preweighed silica gel	

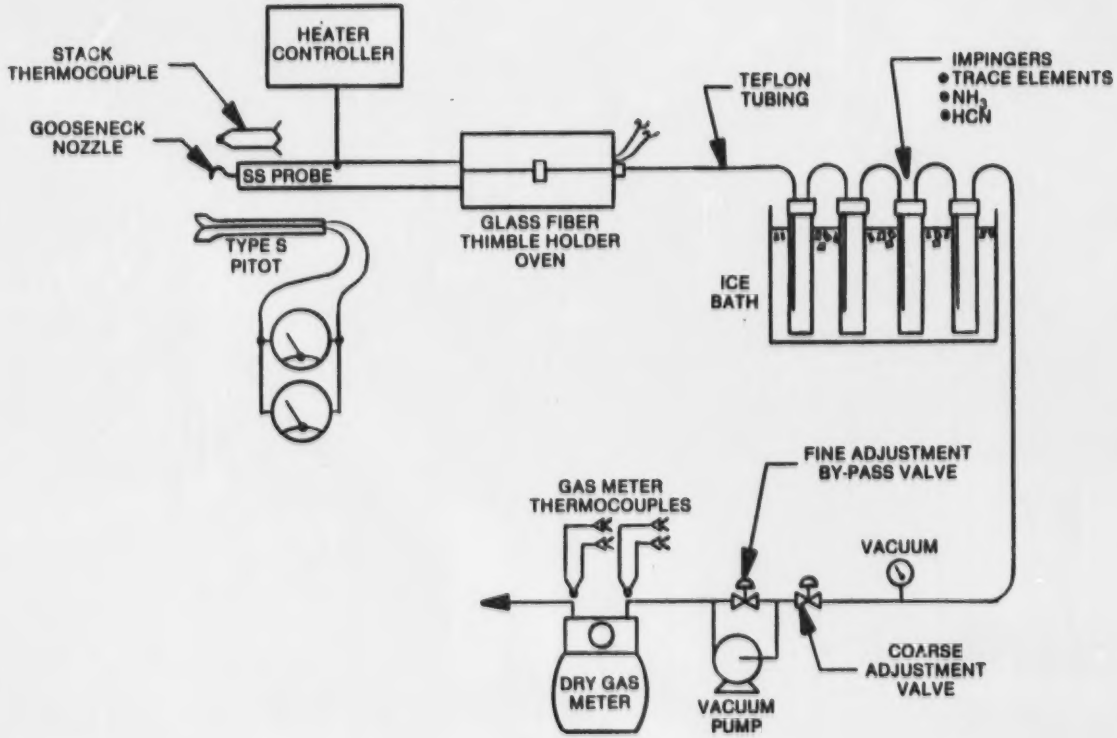
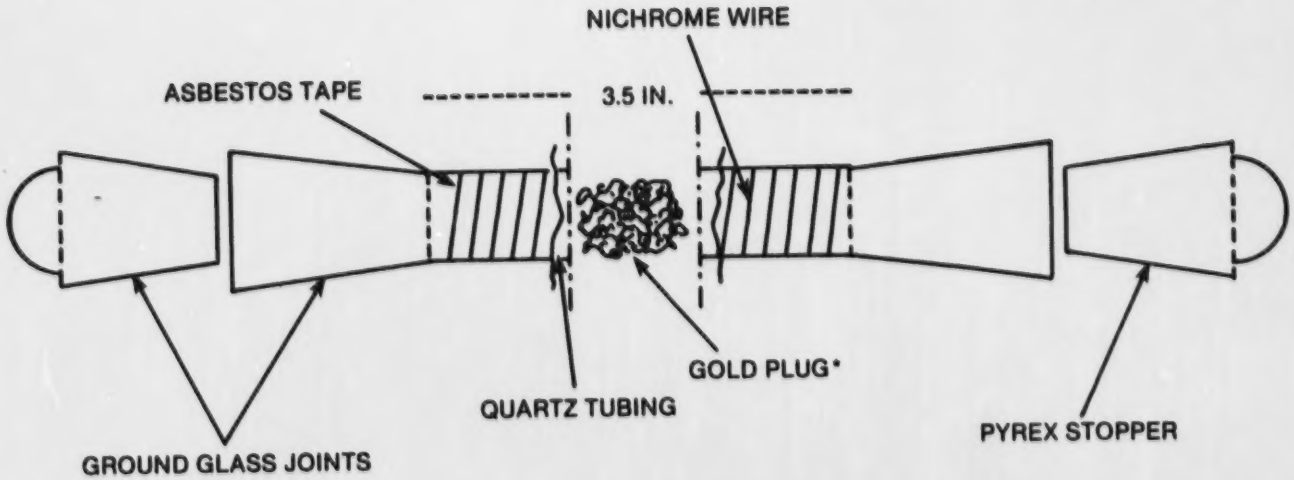


Figure C-6. Sampling system for trace elements, NH_3, and HCN -- cleaned and raw bottom product gas.



*THE GOLD PLUG IS MADE FROM 36-GAUGE GOLD WIRE; 8-10 GRAMS OF WIRE IS SUFFICIENT.

Figure C-7. Mercury sampling tube.

The impinger solutions were analyzed on site by the analytical methods described in Appendix D.

The resulting impinger solutions were treated to remove sulfides and then analyzed on site, as described in Appendix D.

C.2.3.3 Cyanide

The impinger solutions used for cyanide collection were:

1.	10% NaOH	100 mL
2.	10% NaOH	100 mL
3.	Dry	
4.	Preweighed silica gel	

C.2.4 Samples for Gas Chromatographic Analyses and Benzene, Toluene, and Xylene Analysis

The process gases were analyzed on site by gas chromatography for major (fixed) gases, gaseous sulfur species, and C_1-C_6 hydrocarbons as described in Appendix D. The gas samples were collected with a sampling and conditioning apparatus consisting of 1.2 meters of heat-traced Teflon sample line followed by a Teflon membrane filter in a stainless steel filter holder. These were followed by a Perma-pure® drier, a Teflon-lined diaphragm pump, and a flow meter. Silanized glass sample bombs were used to collect the conditioned gas at the exit of the train. Sample bombs were purged, pressurized at >155 kPa (8 psig), and immediately transported to the laboratory for analysis. Benzene, toluene, and xylene (BTX) samples were collected on two-section charcoal tubes in place of the sample bombs using the same sampling system.

C.3.0 COMBUSTION GASES

Two combustion emissions streams were sampled during the test program. These were:

- the combined emissions from Boilers No. 1 and No. 2 firing combined product gas, and
- the emissions from Boiler No. 3 firing ESP oils only and natural gas only.

With the exception of Boiler No. 3 firing natural gas, these streams were sampled for:

- aerosol and particulate,
- vapor phase organics,
- trace elements,
- ammonia and cyanide,
- oxides of sulfur (SO_x),
- oxides of nitrogen (NO_x), and
- fixed gases, C_1-C_6 hydrocarbons, sulfur species, and benzene, toluene, and xylenes.

Samples of emissions from Boiler No. 3 firing natural gas were analyzed for SO_x, NO_x, fixed gases, C_1-C_6 hydrocarbons, and sulfur species.

The combined emissions from Boilers No. 1 and 2 are exhausted through a circular stack 30 meters in height. The combustion gases exit each boiler and are combined in a rectangular duct prior to the stack. Sampling was performed in this duct. Five velocity traverses were performed from five 3-inch sampling ports about 7 meters above the point where the two individual streams are combined. Sampling was performed from a single port at the point of average flue gas velocity. The emissions from Boiler No. 3 are exhausted through a 1.4 meter diameter duct extending about 2.5 meters above the building roof. Two velocity traverses were performed from two 4-inch ports at 90° to each other about 1 meter above the building roof. Sampling was performed on a traverse from each port. The techniques used for taking the various types of samples are discussed below.

C.3.1 Aerosol and Particulates, Vapor Phase Organics and Trace Elements

Aerosol and particulates, vapor phase organics, and trace elements were sampled using a modified EPA Source Assessment Sampling System (SASS train). The train configuration and method of operation meet current specifications (Ref. C-1), except for the location of the XAD-2 canister in the organic module and the use of a single, >1 μm cyclone instead of a series of three cyclones. These procedures currently require that the XAD-2 canister be positioned beneath the gas cooler. In this position, large quantities of aqueous and organic phase condensate flow through the XAD-2 resin and are subsequently trapped in a knock-out below the resin. This arrangement could cool the resin early in the sampling effort and result in reduced collection efficiencies for vapor phase organic material.

The modified configuration shown in Figure C-8 traps condenses material before it passes through the resin, thus reducing the possibility of reduced resin collection efficiency. It also simplifies sample recovery and analysis. The single cyclone was used because very low particle concentrations in the flue gases obviated the need for three cyclones for particle sizing.

Aerosol and particulate loadings were determined from the probe and nozzle rinse, cyclone catch, and filter catch. The organic sample consisted of the probe and nozzle rinses, particulate catch extract, and the sample taken from the organic module consisting of condensate and XAD-2 resin extract.

Trace element samples consisted of aliquots of the organic module samples and the samples collected in the trace element impingers. The impinger solutions used for vapor phase trace element collection were:

1.	0.2M $(NH_4)_2S_2O_8$ + 0.2M $AgNO_3$	750 mL
2.	0.2M $(NH_4)_2S_2O_8$ + 0.2M $AgNO_3$	750 mL
3.	Dry	
4.	Preweighed silica gel	

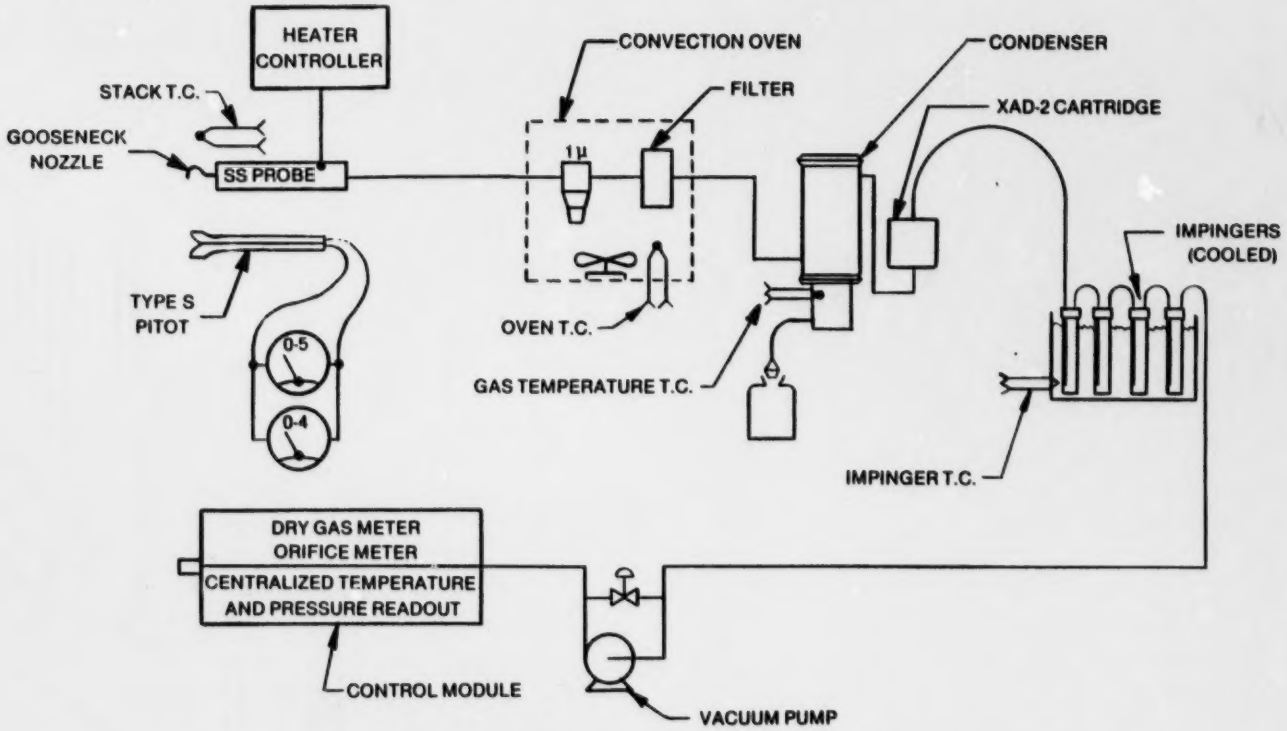


Figure C-8. High volume Source Assessment Sampling System (SASS) -- sampling system for organics and trace elements in combustion emissions from product gas boilers and Boiler No. 3 firing ESP oil.

C.3.2 Ammonia and Cyanide

Samples for analysis of ammonia and cyanide in the flue gas were collected during the SASS run. An auxiliary sampling train shown in Figure C-9 was used. It consisted of a stainless steel probe and a heated 47 mm glass fiber filter. The impinger contents for ammonia were:

1.	10% H_2SO_4	100 mL
2.	10% H_2SO_4	100 mL
3.	Dry	
4.	Preweighed silica gel	

The gas temperature was held at 120°C (250°F) until the gas had been filtered. At the completion of the run, the impinger contents were transferred to sample containers and analyzed on site by the analytical method described in Appendix D.

The auxiliary sampling assembly and sampling methodology used for ammonia collection was also used for cyanides. The impinger solutions used for cyanide collection were:

1.	10% NaOH	100 mL
2.	10% NaOH	100 mL
3.	Dry	
4.	Preweighed silica gel	

The resulting impinger solutions from the runs were treated to remove sulfides and then analyzed on site, as described in Appendix D.

C.3.3 Sulfur Oxides (SO_x)

Oxides of sulfur (SO_x) samples were collected using a combination of EPA Methods 5 and 6 (Ref. C-2). Particulate samples were also collected using this method. The sample gas was drawn isokinetically through a heated probe and heated glass fiber filter. SO_x was collected in an impinger

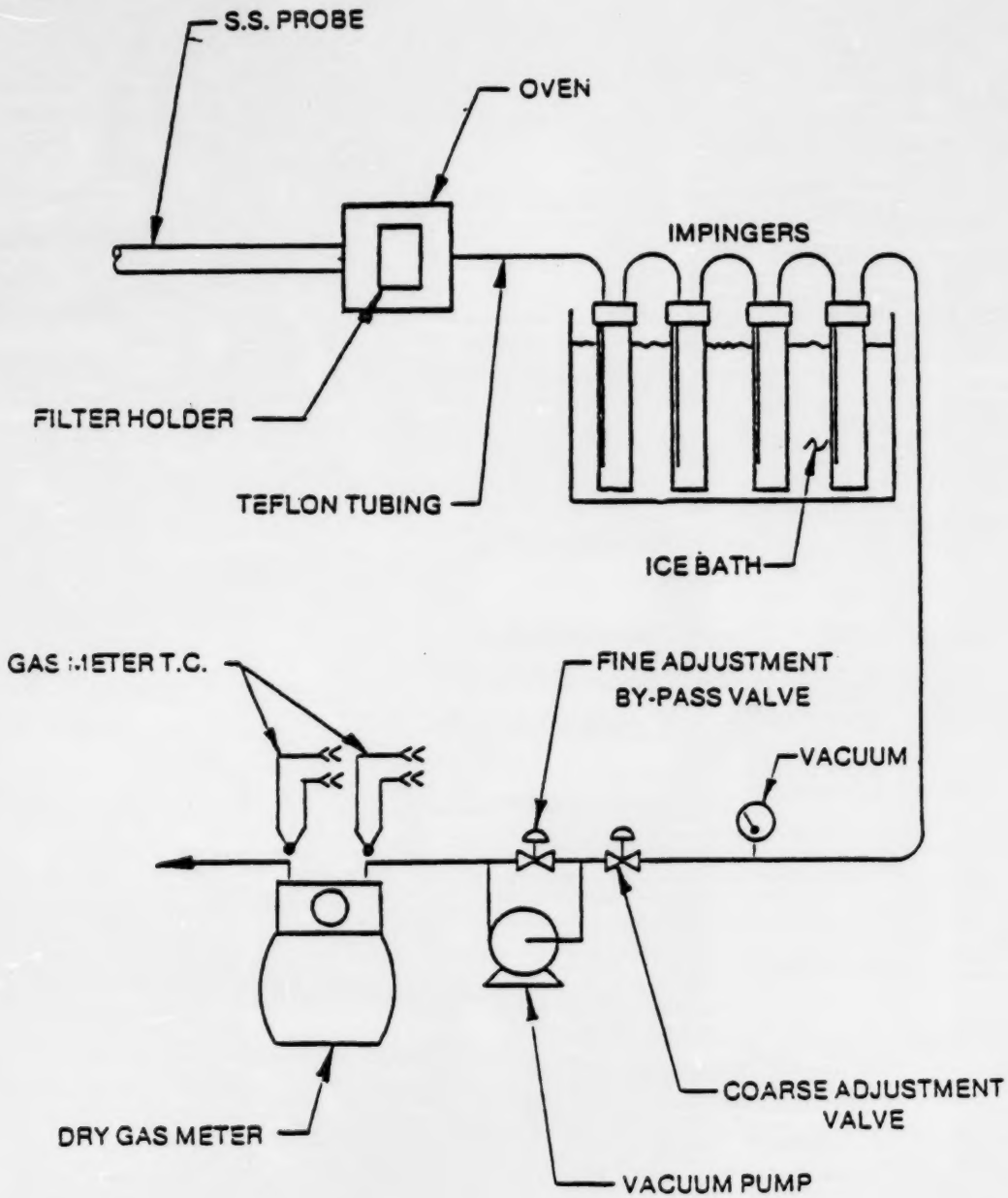


Figure C-9. Schematic drawing of impinger sampling train used for boiler emissions sampling.

train downstream of the filter. The impinger solutions used for collecting SO_x were:

1.	3% H_2O_2	100 mL
2.	3% H_2O_2	100 mL
3.	Dry	
4.	Preweighed silica gel	

The samples were transferred to plastic bottles and analyzed using the method given in Appendix D.

C.3.4 Nitrogen Oxides (NO_x)

Oxides of nitrogen were collected using EPA Method 7 (Ref. C-2). Grab samples of flue gas were taken using a heated glass probe fitted with a glass wool plug. The sample was pulled into an evacuated 2-L flask containing 25 mL of a dilute sulfuric acid-hydrogen peroxide absorbing solution. After taking the sample, the bomb was allowed to sit for 16 hours. The pressure in the flask was measured using a mercury U-tube manometer to determine sample volume. The absorbing solution and water rinses were transferred to a plastic bottle and the pH of the sample was adjusted to between 9 and 12 with 1 N sodium hydroxide. The samples were analyzed on site using the method given in Appendix D.

C.3.5 Fixed Gases, C_1-C_6 Hydrocarbons, Sulfur Species, and Benzene, Toluene, and Xylenes (BTX)

The combustion emission gases were analyzed on site by gas chromatography for major (fixed) gases, gaseous sulfur species, and C_1-C_6 hydrocarbons as described in Appendix D. The gas samples were collected with a sampling and conditioning apparatus consisting of 1.2 meters of heat-traced Teflon sample line followed by a Teflon membrane filter in a stainless steel filter holder. These were followed by a Perma-pure® Drier, a Teflon-lined diaphragm pump, and a flow meter. The Perma-pure® Drier removes moisture from the gas sample by highly selective permeation of water through Nafion® tubing. Silanized glass sample bombs were used to collect the conditioned

gas at the exit of the train. Sample bombs were purged, pressurized to >155 kPa (8 psig) and immediately transported to the laboratory for analysis. BTX samples were collected using charcoal tubes in place of the sample bombs.

C.4.0 SOLIDS

Three solid streams were sampled during the test period. These were:

- coal,
- gasifier ash, and
- cyclone dust.

The sampling techniques used for these streams are discussed below.

C.4.1 Coal

Coal is stored in a series of hoppers inside the heating plant and conveyed from the hoppers to sizing screens located above the coal feed lock-hopper. From the screens, the coal is conveyed to a weigh hopper. Coal samples were collected as the coal fell from the conveyor belt into the weigh hopper. Nine coal samples were taken, three each for three 24-hour periods. The samples were stored in 1-L polyethylene bottles. These samples were composited to form a total of three daily composites for proximate and ultimate analyses, and one weekly composite for trace element analysis. In addition, moisture determinations were performed on each of the nine samples.

C.4.2 Gasifier Ash

Two hydraulically operated buckets remove the gasifier ash from the ash pan and dump the ash onto belt conveyors which transport the ash to a storage area. The ash dewaters through screens which constitute the bottoms of

the buckets. Gasifier ash samples were collected as the ash fell from the buckets onto the conveyor belt. Nine ash samples were collected at approximately the same time that the coal samples were collected. One-liter samples of gasifier ash were stored in two 500-mL glass bottles with Teflon-lined caps.

Moisture determinations were performed on each of the nine samples. The ash samples were composited to form a total of three daily composites for proximate and ultimate analyses, and one weekly composite for trace elements, RCRA leaching, and extractable organics analyses.

C.4.3 Cyclone Dust

Dust removed from the bottom product gas by the cyclone is collected in a lockhopper. The dust is periodically emptied from the lockhopper, augered to drums, and stored for disposal. Samples of the cyclone dust were collected from the auger and stored in 500-mL glass jars with Teflon-lined caps.

Nine cyclone dust samples were taken, three each for the same three 24-hour periods during which ash and coal samples were taken. The individual samples were composited to form three daily composites for proximate and ultimate analyses, and one weekly composite for trace elements, RCRA leaching, and extractable organics analyses.

C.5.0 LIQUIDS

Three liquid streams were sampled during the test period. These were:

- ESP oils from the top product gas,
- ESP oils to Boiler No. 3, and
- ash pan water.

The sampling techniques used for these streams are discussed below.

C.5.1 ESP Oils from Top Product Gas

Oils removed from the top product gas by the electrostatic precipitator (ESP) flow by gravity in heat-traced, insulated lines from the ESP to a heated, insulated, intermediate storage tank. Grab samples of the ESP oil (500 mL) were collected through a valve in the transport line between the ESP and storage tank and were stored in two 250-mL glass bottles with Teflon-lined caps.

Samples were taken during the same three 24-hour periods when the coal, ash, and dust samples were taken. These samples were composited to form three daily composites for proximate and ultimate analyses.

C.5.2 ESP Oils to Boiler No. 3

During the combustion of ESP oils in Boiler No. 3, ESP oils are pumped to the boiler from an underground heated storage tank. Samples of the ESP oils to Boiler No. 3 were collected through a valve mounted in the transfer line between the pump and boiler. Grab samples of the ESP oil to Boiler No. 3 (500 mL) were stored in two 250-mL glass bottles with Teflon-lined caps.

Three samples were taken during the 24-hour period when Boiler No. 3 was firing the oils. This time period was not concurrent with the rest of the three 24-hour sampling periods that took place. The three samples were composited to form a daily composite for density, proximate and ultimate, trace elements, and extractable organics analyses.

C.5.3 Ash Pan Water

Ash pan water samples were collected directly from the ash pan. Eleven samples were collected during the three 24-hour periods when all samples

except ESP oils to Boiler No. 3 were taken. Conductivity and pH were determined for each of these samples. Of the eleven samples, ten were aliquoted into 1-L glass bottles and subsequently composited to form three daily composites for water quality parameters analyses. Seven samples were aliquoted into 1-L glass bottles with Teflon-lined caps and 1-L polyethylene bottles and subsequently composited to form two weekly composites for extractable organics and trace elements analyses, respectively.

REFERENCES

C-1 Lentzen, D.E., D.E. Wagoner, E.D. Estes, and W.F. Gutknecht. IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition). NTIS No. PB-293 795. Research Triangle Institute, Research Triangle Park, North Carolina, 1978. (EPA-600/7-78-201)

C-2 Reference Methods. Appendix A to 40 CFR 60. Environmental Reporter. Bureau of National Affairs, Washington, D.C., December 5, 1980.

APPENDIX D
ANALYTICAL TECHNIQUES

D.1.0 INTRODUCTION

This appendix describes the analytical techniques used for the analysis of samples collected for the assessment of the Foster Wheeler/Stoic gasifier. The analytical matrix for each sample is detailed in Figures D-1 through D-9.

D.2.0 WASTEWATER PARAMETERS AND IONIC SPECIES ANALYSES

D.2.1 Ammonia

Ammonia in the sulfuric acid impinger solutions and water samples was determined on-site by distillation/titrimetric procedures (Ref. D-1.) The sample was initially distilled into an indicating boric acid absorbing solution. The collected distillate was titrated with standard sulfuric acid. The detection limit for the procedure is 1.0 μg/mL ammonia as nitrogen in 200 mL of impinger solution. This is equivalent to 1.1 ppm ammonia by volume collected from 0.28 SCM of sampled gas.

D.2.2 Cyanide

Cyanide was determined on-site by the distillation/colorimetric procedure (Ref. D-1). Interfering sulfide was precipitated from the caustic impinger solutions and water samples with lead nitrate. An acid reflux distillation procedure was used to remove interferences. Distilled hydrogen cyanide was collected in a caustic solution and converted to cyanogen chloride by reaction with chloramine-T. Following complete conversion, pyridine-barbituric acid reagent was added to produce a red-blue dye with

On-site Analysis

Grab Samples

Major Components

- CO, CO_2, H_2, CH_4, O_2+Ar, N_2
  - TCD/GC

Hydrocarbons

- C_1-C_6
  - FID/GC

Sulfur Species

- H_2S, COS, CS_2, SO_2, CH_3SH, C_2H_5SH, C_4H_4S
  - FPD/GC

Integrated Samples

NH_3

- Collected in 5% H_2SO_4
  - distillation/titrimetric

HCN

- Collected in 10% NaOH
  - distillation/colorimetric

Aerosol Loading
(particulate and oil mist)

- Gravimetric

BTX

- Collected on Charcoal
- Extracted with carbon disulfide
  - FID/GC

Trace Elements

- Collected in 0.2 M $(NH_4)_2S_2O_8$-$AgNO_3$
  - ICPES
  - AAS
  - SSMS

Extractable Organics

- Collected in water cooled condenser and on XAD-2 resin
- Extracted with methyene chloride and diethyl ether
  - Total organic loading
    - TOO (100-300°C boiling range)
      - FID/GC
    - GRAV (>300°C boiling range)
      - gravimetric
  - Polychlorinated biphenyls
    - ECD/GC
  - Organic halogens, sulfur, nitrogen
    - HECD/GC
  - Compound identification and quantitation
    - GC/MS (priority pollutant protocol analysis)
  - Liquid chromatography fractionation
    - seven fractions
      - TOO
      - GRAV

Figure D-1. An analytical matrix for combined product gas from the Foster Wheeler/Stoic two-stage gasifier (UMD).

On-site Analysis

Grab Samples

Major Components

- CO, CO_2, H_2, CH_4, O_2+Ar, N_2
  - TCD/GC

Hydrocarbons

- C_1-C_6
  - FID/GC

Sulfur Species

- H_2S, COS, CS_2, SO_2, CH_3SH, C_2H_5SH, C_4H_4S
  - FPD/GC

NO_x

- EPA Method 7

Integrated Samples

SO_2

- EPA Method 6

NH_3

- Collected in 5% H_2SO_4
  - distillation/titrimetric

HCN

- Collected in 10% NaOH
  - distillation/colorimetric

Particulate Loading

- EPA Method 17

BTX

- Collected on Charcoal
- Extracted with carbon disulfide
  - FID/GC

Trace Elements

- Collected in 0.2 M $(NH_4)_2S_2O_8$-$AgNO_3$
  - ICPES
  - AAS
  - SSMS

Extractable Organics

- Collected in water cooled condenser and on XAD-2 resin
- Extracted with methyene chloride and diethyl ether
  - Total organic loading
    - TCO (100-300°C boiling range)
      - FID/GC
    - GRAV (>300°C boiling range)
      - gravimetric
  - Polychlorinated biphenyls
    - ECD/GC
  - Organic halogens, sulfur, nitrogen
    - HECD/GC
  - Compound identification and quantitation
    - GC/MS (priority pollutant protocol analysis)

Figure D-2. An analytical matrix for combustion emissions from the product gas boilers and Boiler No. 3 firing ESP oils.

On-Site Analysis

Grab Samples

Major Components

- CO, CO_2, H_2, CH_4, O_2+Ar, N_2
  - TCD/GC

Hydrocarbons

- C_1-C_6
  - FID/GC

Sulfur Species

- H_2S, COS, CS_2, SO_2, CH_3SH, C_2H_5SH, C_4H_4S
  - FPD/GC

Integrated Samples

NH_3

- Collected in 5% H_2SO_4
  - distillation/titrimetric

HCN

- Collected in 10% NaOH
  - distillation/colorimetric

Particulate Loading

- EPA Method 17

Aerosol Loading
(particulate and oil mist)

- Gravimetric

Figure D-3. An analytical matrix for cleaned and raw top product gas and cleaned and raw bottom product gas from the Foster Wheeler/Stoic two-stage gasifier (UMD).

Individual Samples		Daily Composites		Weekly Composites	
2/24	1945 hrs.	2/24	1945 hrs.	2/24	1945 hrs.
2/25	0145 hrs.	2/25	0145 hrs.	2/25	0145 hrs.
2/25	0615 hrs.	2/25	0615 hrs.	2/25	0615 hrs.
2/27	1035 hrs.	2/27	1035 hrs.	2/27	1035 hrs.
2/27	1350 hrs.	2/27	1350 hrs.	2/27	1350 hrs.
2/27	1825 hrs.	2/27	1825 hrs.	2/27	1825 hrs.
3/05	1240 hrs.	3/05	1240 hrs.		
3/05	1540 hrs.	3/05	1540 hrs.		
3/05	2040 hrs.	3/05	2040 hrs.		
	Moisture		Proximate/ Ultimate		Trace Elements -ICPES -AAS -SSMS

Figure D-4. An analytical matrix for coal from the Foster Wheeler/Stoic two-stage gasifier (UMD).

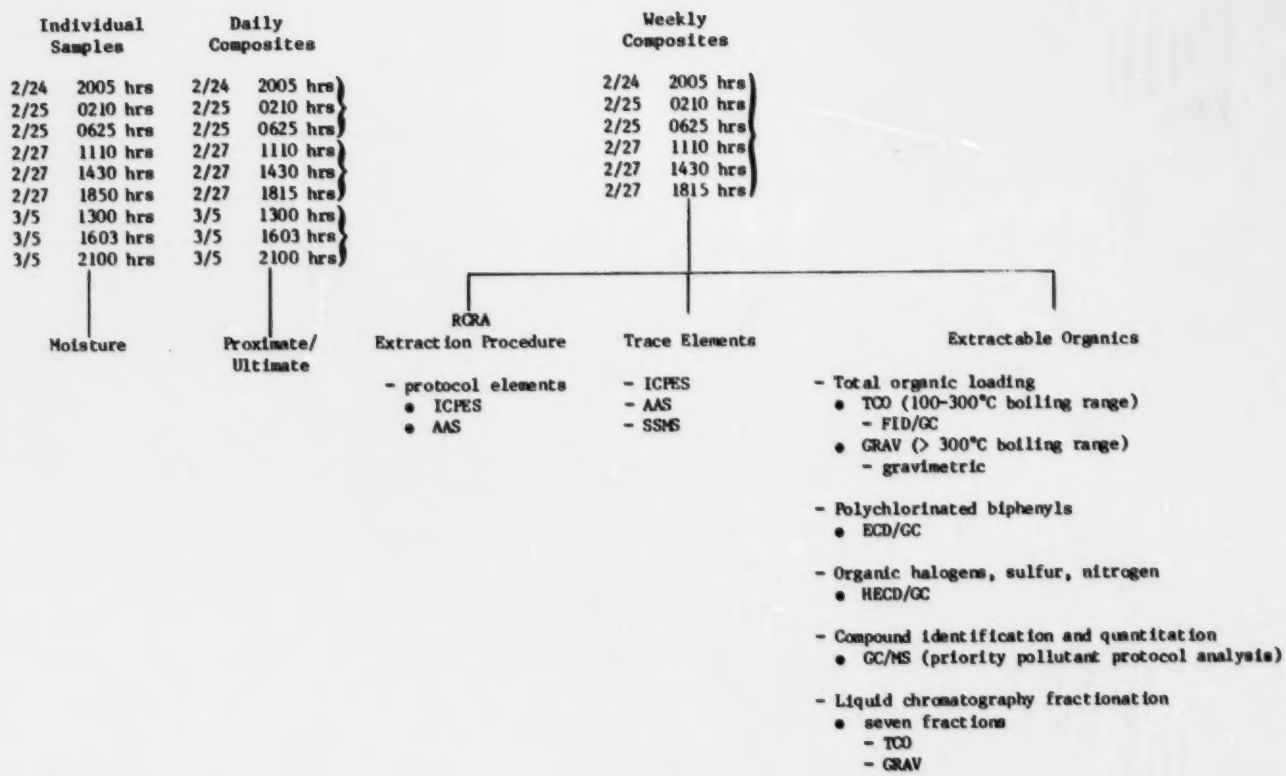


Figure D-5. An analytical matrix for gasifier ash from the Foster Wheeler/Stoic two-stage gasifier (UMD).

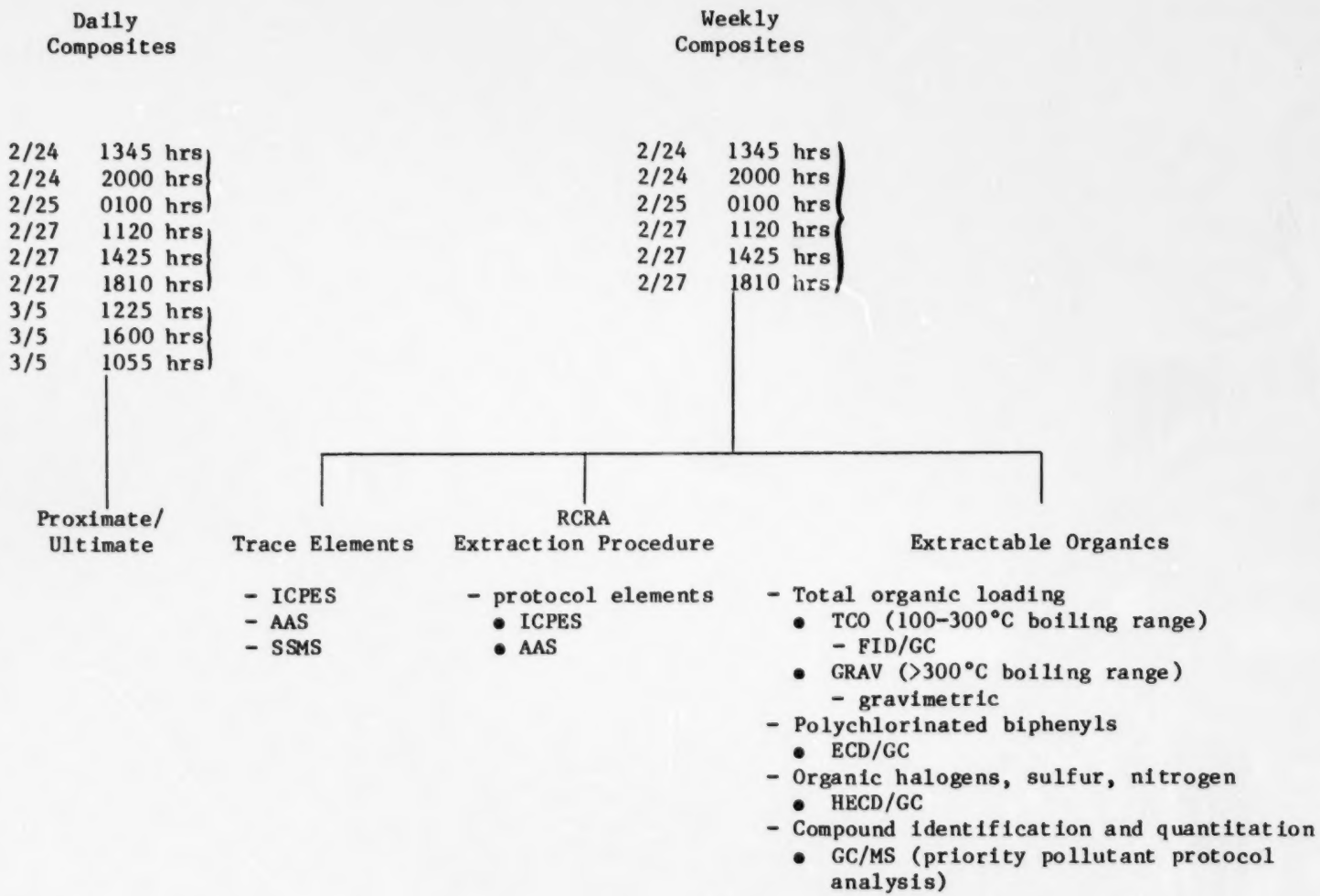


Figure D-6. An analytical matrix for cyclone dust from the Foster Wheeler/Stoic two-stage gasifier (UMD).

Daily
Composite

3/3 1115 hrs
3/3 1240 hrs
3/3 1925 hrs

Density

Proximate/ Ultimate

Trace Elements

- ICPES
- AAS
- SSMS

Extractable Organics

- Total organic loading
  - TCO (100-300°C boiling range)
    - FID/GC
  - GRAV (>300°C boiling range)
    - Gravimetric
- Polychlorinated biphenyls
  - ECD/GC
- Organic halogens, sulfur, nitrogen
  - HECD/GC
- Compound identification and quantitation
  - GC/MS (priority pollutant protocol analysis)
- Liquid chromatography fractionation
  - Seven fractions
    - TCO
    - GRAV

Figure D-7. An analytical matrix for ESP Oils to Boiler No. 3 from the Foster Wheeler/Stoic two-stage gasifier (UMD).

Daily
Composites

2/24	1640 hrs
2/24	2005 hrs
2/25	0155 hrs
2/27	1430 hrs
2/27	1805 hrs
3/5	1245 hrs
3/5	1550 hrs
3/5	2025 hrs

Proximate/
Ultimate

Figure D-8. An analytical matrix for ESP oils from the Foster Wheeler/Stoic two-stage gasifier (UMD).

Individual Samples

2/24	1100 hrs
2/24	1600 hrs
2/24	2020 hrs
2/25	0200 hrs
2/25	0620 hrs
2/26	
2/27	1115 hrs
2/27	1420 hrs
2/27	1735 hrs
3/5	1250 hrs
3/5	1555 hrs
3/5	2100 hrs

pH
Conducitivity

Daily Composites

2/24	1600 hrs
2/24	2020 hrs
2/25	0200 hrs
2/25	0620 hrs
2/27	1115 hrs
2/27	1420 hrs
2/27	1735 hrs
3/5	1250 hrs
3/5	1555 hrs
3/5	2100 hrs

Water
Quality
Parameters

Weekly Composites

2/24	1600 hrs
2/24	2020 hrs
2/25	0200 hrs
2/25	0620 hrs
2/27	1115 hrs
2/27	1420 hrs
2/27	1735 hrs

Trace Elements

- ICPES
- AAS
- SSMS

Extractable Organics

- Total organic loading
  - TCO (100-300°C boiling range)
    - FID/GC
  - GRAV (> 300°C boiling range)
    - gravimetric
- Polychlorinated biphenyls
  - ECD/GC
- Organic halogens, sulfur, nitrogen
  - HECD/GC
- Compound identification and quantitation
  - GC/MS (priority pollutant protocol analysis)

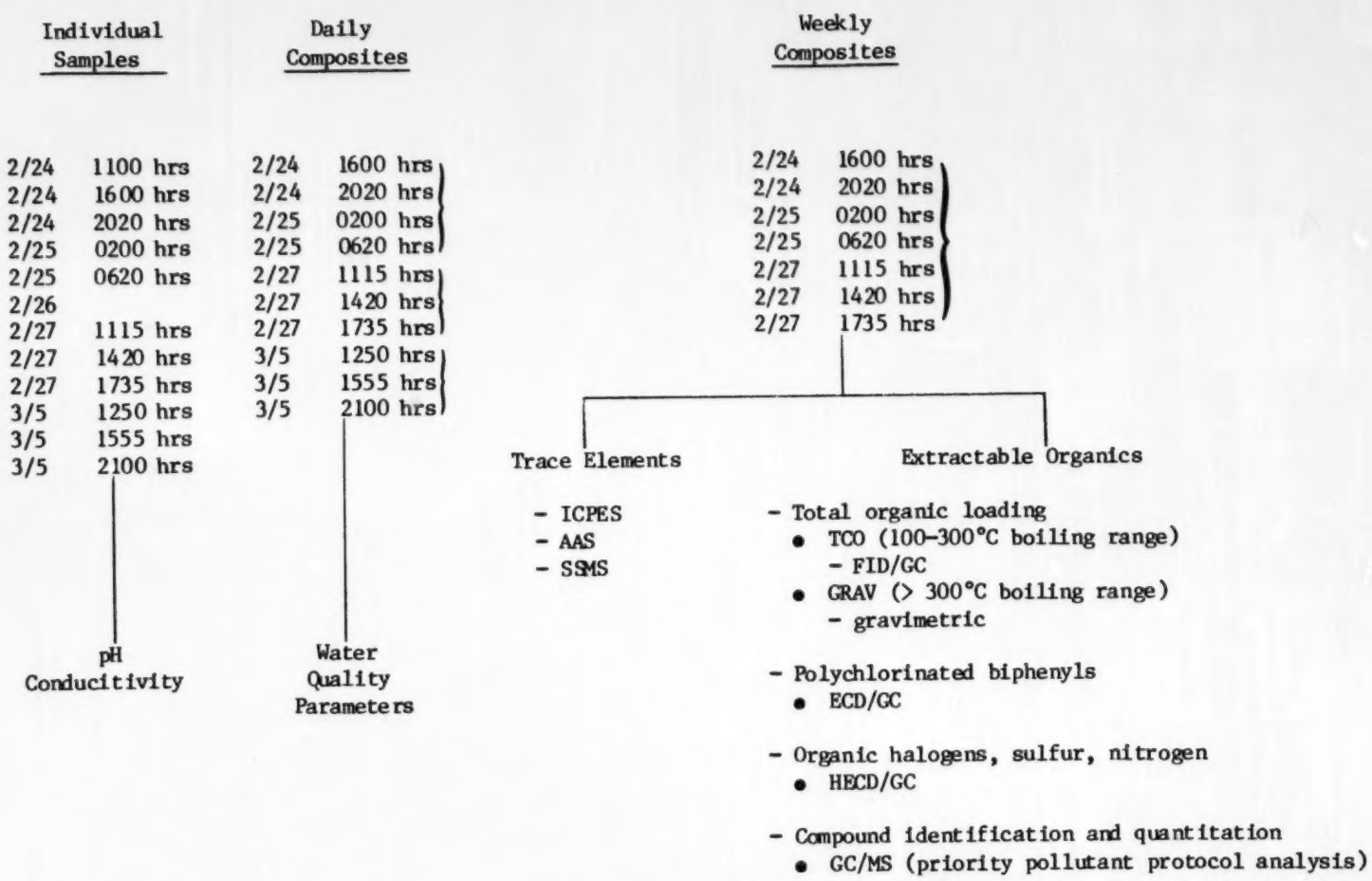


Figure D-9. Analytical results for ash pan water from the Foster Wheeler/Stoic two-stage gasifier (UMD).

absorbance at 578 nm. Cyanide in the range of 1-10 μg was determined spectrophotometrically by comparison with a standard calibration curve generated from potassium cyanide standard solutions. The detection limit for the procedure is .02 μg/mL cyanide in the diluted distillate. This is equivalent to 20 ppb hydrogen cyanide by volume collected from 0.28 SCM of sampled gas in 200 mL of impinger solution.

D.2.3 Thiocyanate

Thiocyanate was determined colorimetrically using the same samples used for cyanide analysis (Ref. D-3). An aliquot of the sample solution was extracted with chloroform to remove organic compounds. A solution of copper and pyridine was added to the aqueous layer to form a copper dithiocyanato-pyridine complex. The complex was extracted with chloroform and determined spectrophotometrically at 407 nm by comparison to a calibration curve generated from standard solutions. The detection limit for the procedure is 4 μg/mL thiocyanate. This is equivalent to 2.7 ppm thiocyanate by volume collected from 0.28 SCM of sampled gas in 200 mL of impinger solution.

D.2.4 Fluoride

Baker (Ref. D-3), Bauman (Ref. D-4), and Thomas (Ref. D-5), describe standard addition techniques using a specific ion electrode for the measurement of fluoride in aqueous samples. A citrate buffer was added to the sample to buffer both pH and ionic strength. Fluoride bound in metal complexes was released by the buffer. Fluoride concentration was related to potential changes which were measured using an Orion Model 94-09A solid-state fluoride electrode and a Corning Model 125 pH/millivolt meter. A detection limit of 0.05 μg/mL is reported.

D.2.5 Phosphate

Total phosphate was determined by the persulfate digestion/single reagent colorimetric method (Ref. D-1). Aqueous samples were boiled with

ammonium persulfate and sulfuric acid to convert all oxidizable phosphorus compounds to the orthophosphate form. The resulting solutions were then treated with a single reagent containing ammonium molybdate, antimony, potassium tartrate, and ascorbic acid for color development. This reagent forms an antimony phosphomolybdate complex when reacted with orthophosphate solutions under acidic conditions. The complex was reduced by ascorbic acid to an intensely blue complex which is measured spectrophotometrically and compared to two standard calibration curves. The detection limit for the method was 0.5 μg PO_4-P/mL.

D.2.6 Chloride

Chloride was determined spectrophotometrically according to ASTM methodology [Designation D-512-67 (1974), Method C (Ref. D-6)]. An aliquot of sample was treated successively with a ferric ammonium sulfate solution and a mercuric thiocyanate solution. The intensity of the red ferric thiocyanate complex formed was measured at 463 nm using the Spectronic 20 and a 1 cm cell. Calibration curves were prepared by analyzing aliquots of standards containing 1-10 μg Cl/mL.

D.2.7 Nitrate

Nitrate was determined colorimetrically using the standard method (Ref. D.1). Nitrate reacts with chromotropic acid to form a yellow reaction product which was measured spectrophotometrically at 410 nm and compared to standards ranging from 1-10 μg NO_3-N/mL. A detection limit of 1.0 μg NO_3-N/mL was reported.

D.2.8 Sulfate

In aqueous samples, sulfate was determined by the addition of barium chloride (Ref. D-1). The resulting turbid solution was analyzed spectrophotometrically at 420 nm. Standard curves were prepared for sample quantitation. A detection limit of 5 μg/mL was reported.

Sulfur dioxide and sulfur trioxide in gaseous streams were analyzed as sulfate. Both gas species were adsorbed and oxidized to sulfate in hydrogen peroxide impinger solutions (Ref. D-7). The solutions were then titrated with standard barium perchlorate solution with thorin as an indicator. A detection limit of 3.4 mg SO_2/m^3 was reported.

D.2.9 Sulfite-Sulfide

Total sulfite and sulfide in aqueous samples were analyzed by titrating with a standardized potassium iodide-iodine solution with starch as an end-point indicator (Ref. D-1). Sulfide in the impinger solutions was precipitated as zinc sulfide with zinc acetate under alkaline conditions. The zinc sulfide was removed by filtration, transferred to a flask, and an excess of a standard iodine solution was added. The excess iodine was then back-titrated with sodium thiosulfate to a starch end-point to determine the amount of iodine consumed by sulfide (Ref. D-1). The filtrate was titrated with a standard iodine-iodate solution. The detection limit was 2 μg S-/mL and 2.5 μg SO_3/mL.

D.2.10 Chemical Oxygen Demand (COD)

Chemical oxygen demand was determined by the standard method (Ref. D-1) by refluxing the sample with potassium dichromate and sulfuric acid for two hours. After cooling, the excess dichromate was titrated with ferrous ammonium sulfate. The amount of potassium dichromate consumed is proportional to the amount of oxidizable organic matter in the sample.

D.2.11 Total Organic Carbon (TOC)

Total organic carbon (TOC) was determined with a Beckman Model 915-B carbon analyzer. Total organic carbon in the sample was converted to CO_2 by a process of oxidative combustion, and the CO_2 concentration was measured by a non-dispersive infrared detector. Because all carbon in the sample is measured, procedural modifications are needed to limit the

determination of organic carbon. Inorganic carbonates were removed by acid sparging the sample prior to the analysis for TOC (Reference D-1).

D.2.12 Biological Oxygen Demand (BOD)

BOD is a measure of the change in the amount of dissolved oxygen in a sample when incubated in the dark at 20°C for five days (Ref. D-1). This change in dissolved oxygen was related to the amount of organic matter assimilated and oxidized by microorganisms. An initial dissolved oxygen concentration was determined, and after five days, a final concentration was determined.

D.2.13 Total Suspended Solids (TSS)

TSS was determined using the standard method (Ref. D-1). The sample was filtered through a fine glass fiber filter. The resulting residue on the filter was dried to constant weight at 105°C. The mass of solids per liquid volume was reported as total suspended solids in mg/L.

D.2.14 Total Dissolved Solids (TDS)

TDS was determined using the standard method (Ref. D-1). The filtrate from the TSS determination was evaporated to dryness. The resulting residue was heated to constant weight at 180°C. The mass of solids per liquid volume was reportd as TDS at 180°C in units of mg/L.

D.2.15 pH Value

Hydrogen ion activity was determined electrometrically by the standard method (Ref. D-1) using a Corning Model 125 pH meter with a combination electrode.

D.2.16 Specific Conductance

The specific conductance of a sample was measured by the standard method (Ref. D-1) using a YSI Model 33 conductivity meter. Samples were either analyzed at 25°C, or temperature corrections were made to standardize reporting.

D.2.17 NO_x Analysis

The nitrogen oxide content of a sample was determined using EPA Method 7 (Ref D-7). The gas sample was collected in evacuated 2-L flasks containing a sulfuric acid-hydrogen peroxide absorbing solution which converts NO to NO_2. The sample was basified and the NO_2 concentration determined colorimetrically using phenoldisulfonic acid. Sample absorbance was compared to measured absorbance of potassium nitrate standards at 410 nm.

D.2.18 Phenols

Phenols were analyzed in aqueous samples by the standard method (Ref. D-1). Interferences were removed from the sample by distilling the phenols. The phenols in the distillate were reacted with 4-aminoantipyrine at pH 10 in the presence of potassium ferricyanide to form a colored antipyrine dye. This dye was extracted with chloroform and the absorbance was measured spectrophotometrically at 460 nm. A detection limit of 10 μg/mL was reported.

D.3.0 ELEMENTAL ANALYSIS

D.3.1 Spark Source Mass Spectrometry (SSMS)

Trace metals in the gas, liquid, and solid streams were analyzed by spark source mass spectrometry. Gas samples were collected by SASS train in impingers containing silver persulfate solution (Ref. D-8). The impinger volumes were determined, and aliquots that represented a constant volume of

gas were removed from each impinger in the sample train. Aliquots of the liquid and solid samples were sent directly for SSMS with no additional sample preparation. XAD-2 resin samples were extracted with methylene chloride and diethyl ether and analyzed like the liquid samples.

D.3.2 Antimony, Arsenic, Selenium, and Mercury

The volatile elements were analyzed directly from the composite impinger and aqueous samples by atomic absorption spectrophotometry (AAS). Solids were digested in perchloric acid, dried, and dissolved in hydrochloric acid; the resultant solutions were analyzed by graphite furnace atomic absorption.

Arsenic, antimony, and selenium were analyzed in liquid samples using a hydride generation attachment for the atomic absorption spectrophotometer (Ref. D-8). An aliquot of sample was introduced into the system and acidified. Sodium borohydride was added to reduce the species to the hydride. The generated gas was purged into a hydrogen-argon flame for analysis.

The absorbances and detection limits for the hydride generation method are show below:

Element	Wavelength	Detection Limit (ng/mL of solution)
As	193.7 nm	3 ppb
Sb	217.0 nm	5 ppb
Se	196.0 nm	4 ppb

Mercury in samples of coal, ash, cyclone dust, and tar were determined by ignition in an oxygen bomb with absorption in $KMnO_4$. The resultant solution was analyzed according to "Chemical Analysis of Water and Wastes," U.S. EPA, March, 1979 (Ref. D-9), which involves treatment with potassium persulfate and subsequent reduction of the mercury with stannous chloride and analysis by cold vapor atomic absorption. The ash pan water composite was analyzed directly without the oxygen bomb preparation.

Mercury in gas streams was collected on gold plugs and analyzed by thermal desorption of the mercury from the gold plug. An argon carrier gas swept the mercury into an absorption cell of an atomic absorption spectrometer and the resultant peak was recorded. Gas phase mercury standards obtained by withdrawing various volumes of gas from a sealed bottle saturated with mercury vapor were used for calibration.

D.3.3 Inductively Coupled Argon Plasma Emission Spectrometry (ICPES)

Samples of ash pan water, ESP tar to Boiler No. 3, trace metal impingers, the impinger blank, and perchloric acid digestions of coal, gasifier ash, and cyclone dust were analyzed by ICPES. Solid samples for boron determintion were prepared by sodium carbonate fusion and dissolution in dilute hydrochloric acid. The solutions were aspirated into an argon plasma; the high temperature of plasma (10,000°C) induces electronic excitation of the atoms. The emitted light was passed through a slit and diffracted by a grating. Photomultiplier tubes were set at the characteristic wavelengths of the elements measured.

D.3.4 Proximate/Ultimate Analysis

Proximate/ultimate analyses, subcontracted to Commercial Testing and Engineering Co., Chicago, Illinois, were performed on composites of coal, cyclone dust, gasifier ash, and ESP oil by ASTM methods (Ref. D-10).

D.4.0 LEACHING STUDIES

Gasifier ash and cyclone dust were extracted using the Resource Conservation and Recovery Act (RCRA) procedure as outlined in the Federal Register of December 18, 1978, "Hazardous Wastes, Proposed Guidelines and Regulations" (Ref. D-11). One hundred grams of the air-dried solid were weighed into a polyethylene bottle and 1.6 kg of deionized water was added. The pH was adjusted to 5.0 with Ultrex glacial acetic acid. The pH was monitored for one hour and adjusted as needed to maintain the pH 5.0 level.

The sample was agitated for 24 hours with a rotary shaker. At the end of the 24-hour leaching, the samples were filtered through a 0.45 μm Millipore filter. The filtrate was diluted to 2 kg water. The dilute filtrates were analyzed for trace elements by ICPES and AAS.

D.5.0 GAS CHROMATOGRAPHY

Grab samples of the combined gas, clean top gas, dirty top gas, clean bottom gas, dirty bottom gas, main stack combustion emissions, and combustion emissiosn from Boiler No. 3 firing ESP oil and natural gas were analyzed for the following components:

- fixed gases: H_2, O_2+Ar, N_2, CO_2, CO, and CH_4,
- volatile sulfur species: H_2S, COS, SO_2, CH_3SH, C_2H_5SH, C_4H_4S, and CS_2,
- light hydrocarbons: C_1 to C_6, boiling range -160°C to 80°C

The samples were taken in silanized glass sample bombs and analyzed immediately.

D.5.1 Volatile Sulfur Species

The instrument operating parameters for the analysis of volatile sulfur species were:

Instrument:	Tracor Model 560 FPD-GC
Column:	10 ft x 1/8 inch OD Teflon, 1% TCEP [1,2,3-tris(cyanoethoxy) propane] and 0.5% H_3PO_4 on Carbopack B, 60/80 mesh
Carrier:	Nitrogen at 20 mL/min
Detector Temperature:	150°C
Oven Program:	30°C for 7 min.; 10°C/min to 120°C; 120°C for 10 min.

Standard samples were generated on site using Metronics permeation tubes with certified permeation rates and zero grade nitrogen at known flows. Figures D-10 through D-16 show calibration curves for H_2S, COS, SO_2, CH_3SH, C_2H_5SH, C_4H_4S, and CS_2.

D.5.2 Fixed Gases

The fixed gas analyses were conducted under the following conditions:

Instrument:	Fisher Gas Partitioner Model 1200-TCD-GC
Column 1:	6 1/2 ft. x 1/8 inch OD, Porapak PQ
Column 2:	11 ft x 3/16 inch OD, Molecular Sieve 13X
Carrier:	8.5% Hydrogen in Helium at 28 mL/min
Oven Temperature:	50°C
Bridge Current:	225 mA

The instrument calibration for the fixed gases was performed on site using certified gas mixtures containing the species of interest. The certified gas mixtures supplied by Scientific Gas Products had the following composition:

Species	STD #1	STD #2	STD #3
CO_2	19.7%	10.1%	1.99%
H_2	29.8%	9.90%	19.8%
O_2+Ar	0.85%	0.97%	1.97%
N_2	24.33%	64.99%	34.06%

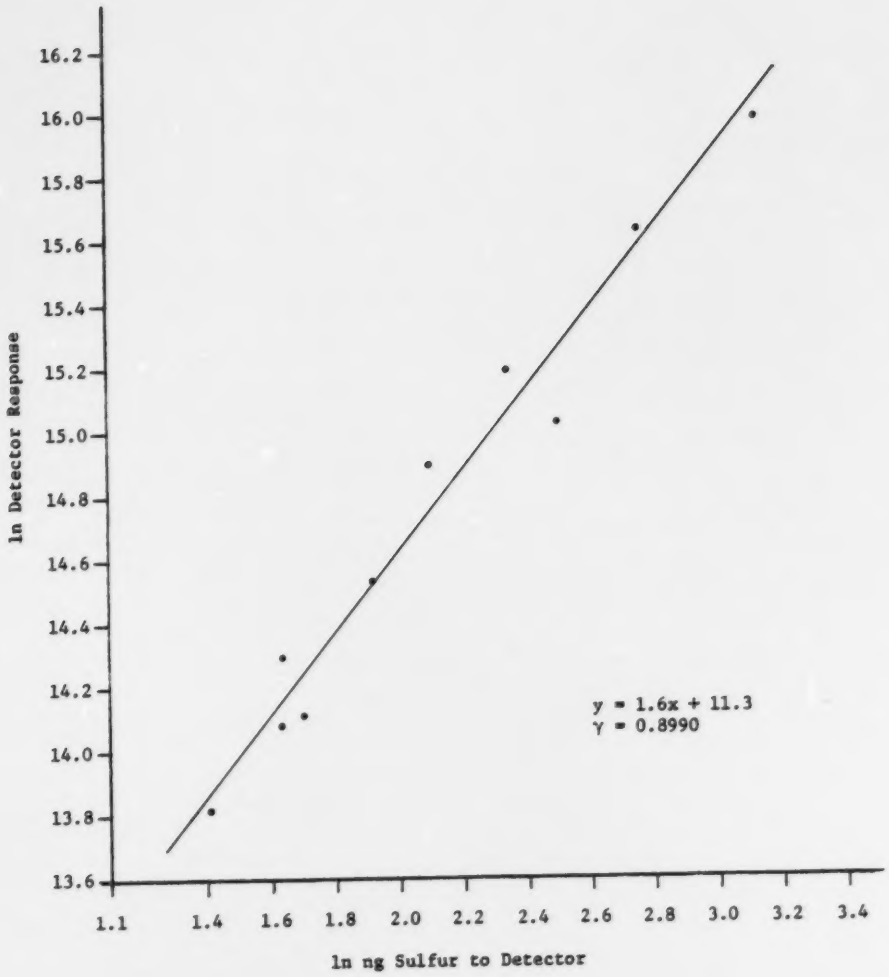


Figure D-10. Hydrogen sulfide (H_2S) calibration curve.

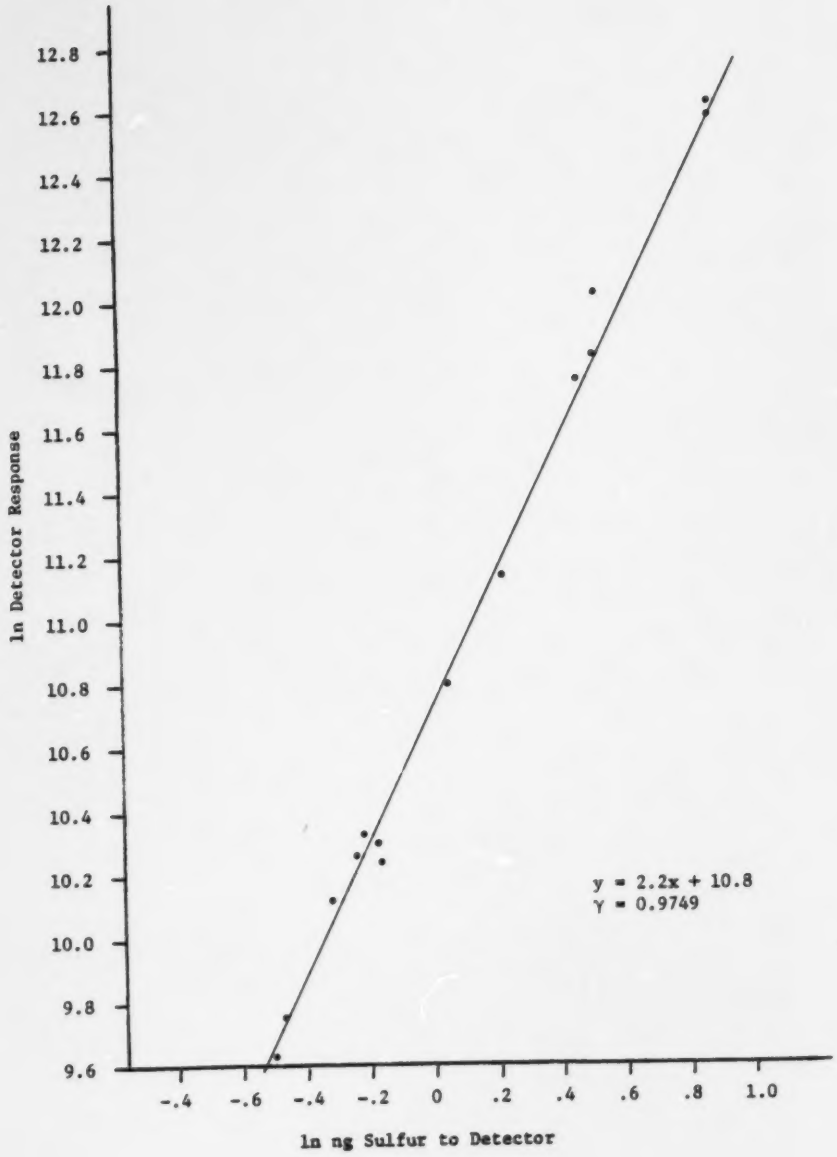


Figure D-11. Carbonyl sulfide (COS) calibration curve.

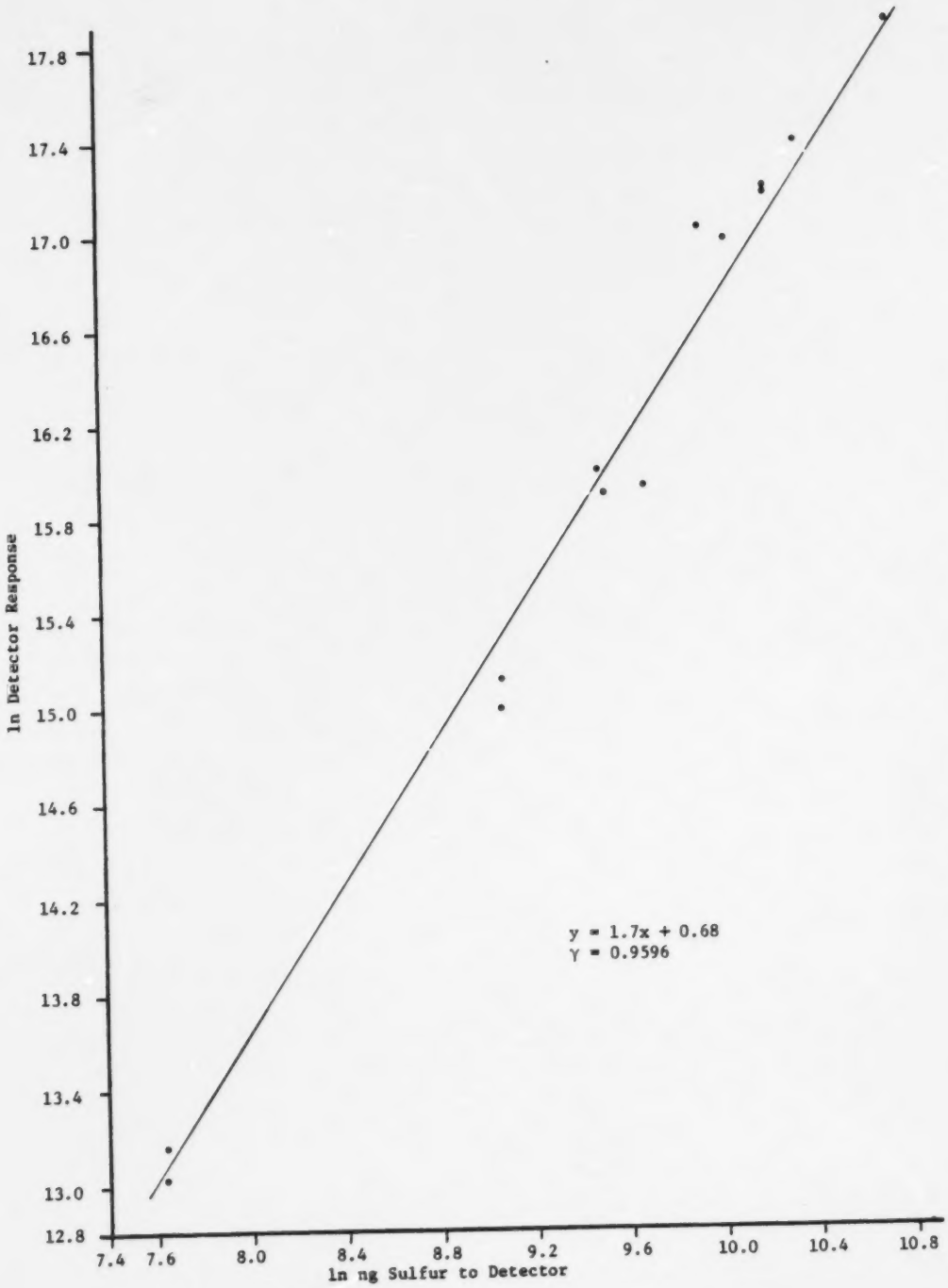


Figure D-12. Sulfur dioxide (SO_2) calibration curve.

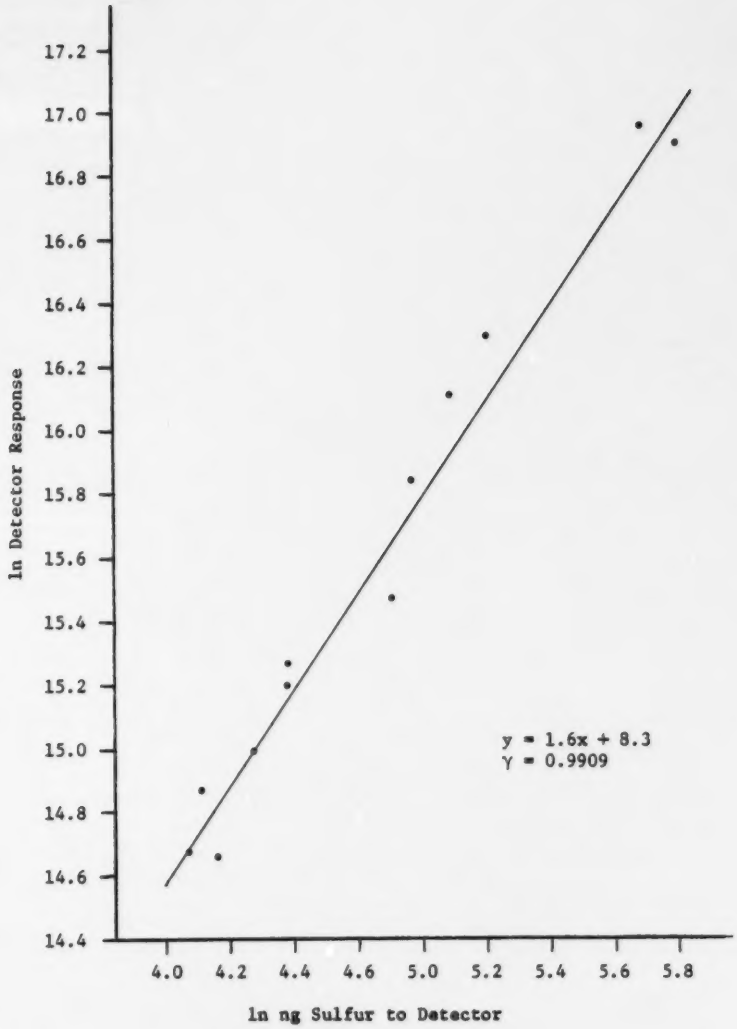


Figure D-13. Methyl mercaptan (CH_3SH) calibration curve.

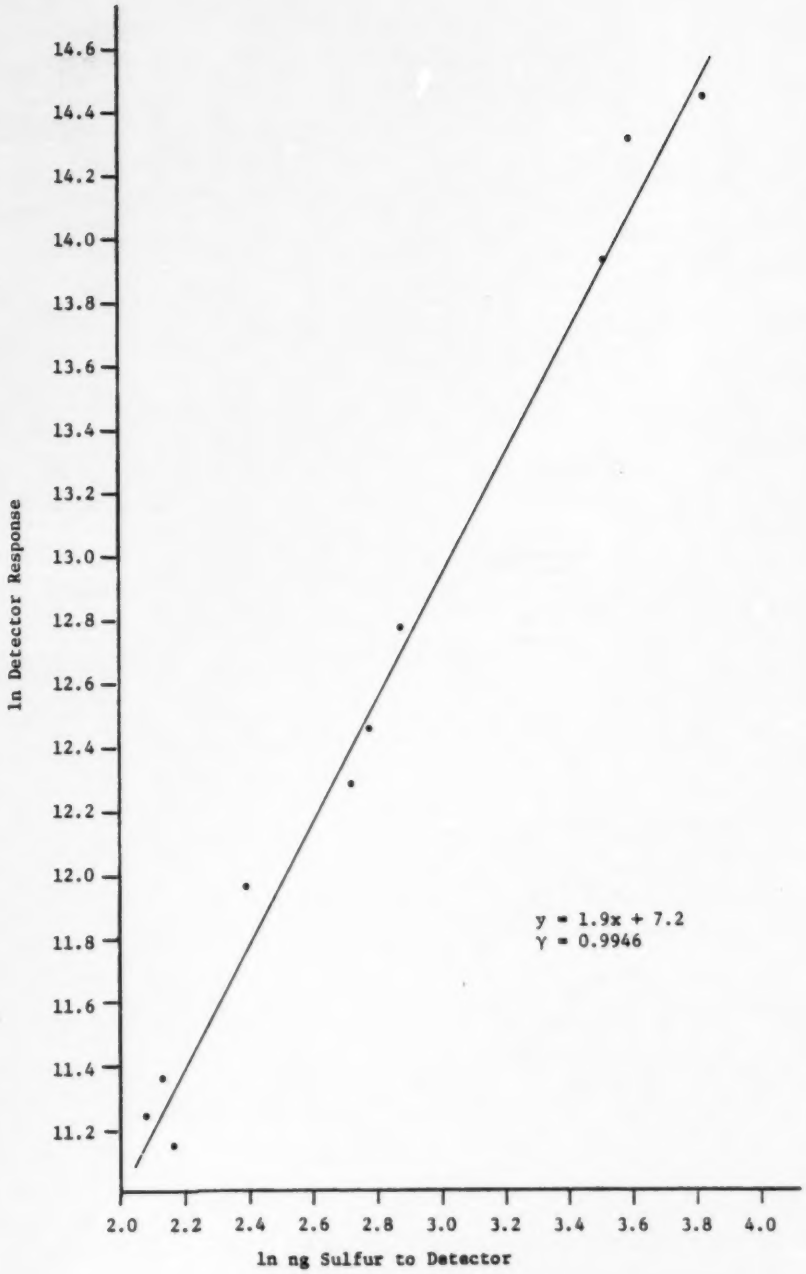


Figure D-14. Ethyl mercaptan (C_2H_5SH) calibration curve.

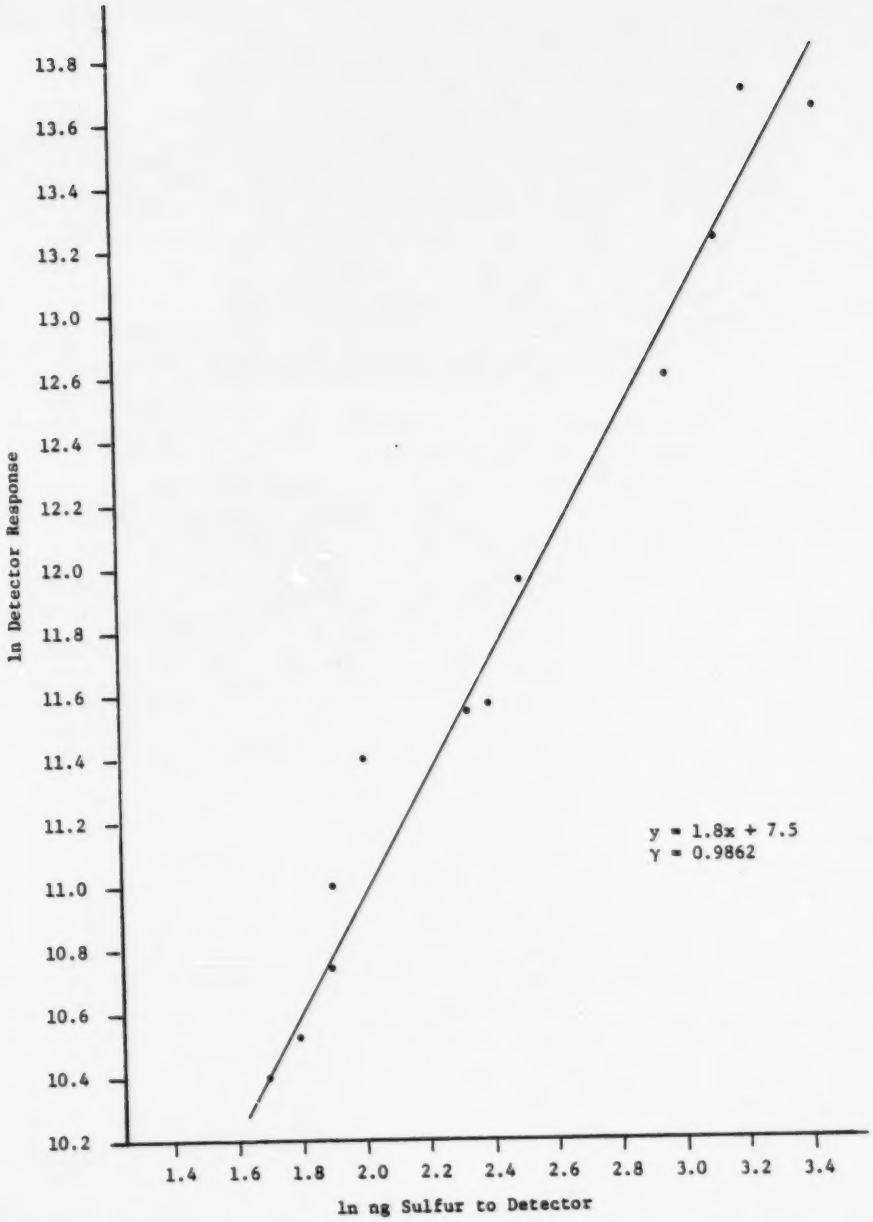


Figure D-15. Thiophene (C_4H_4S) calibration curve.

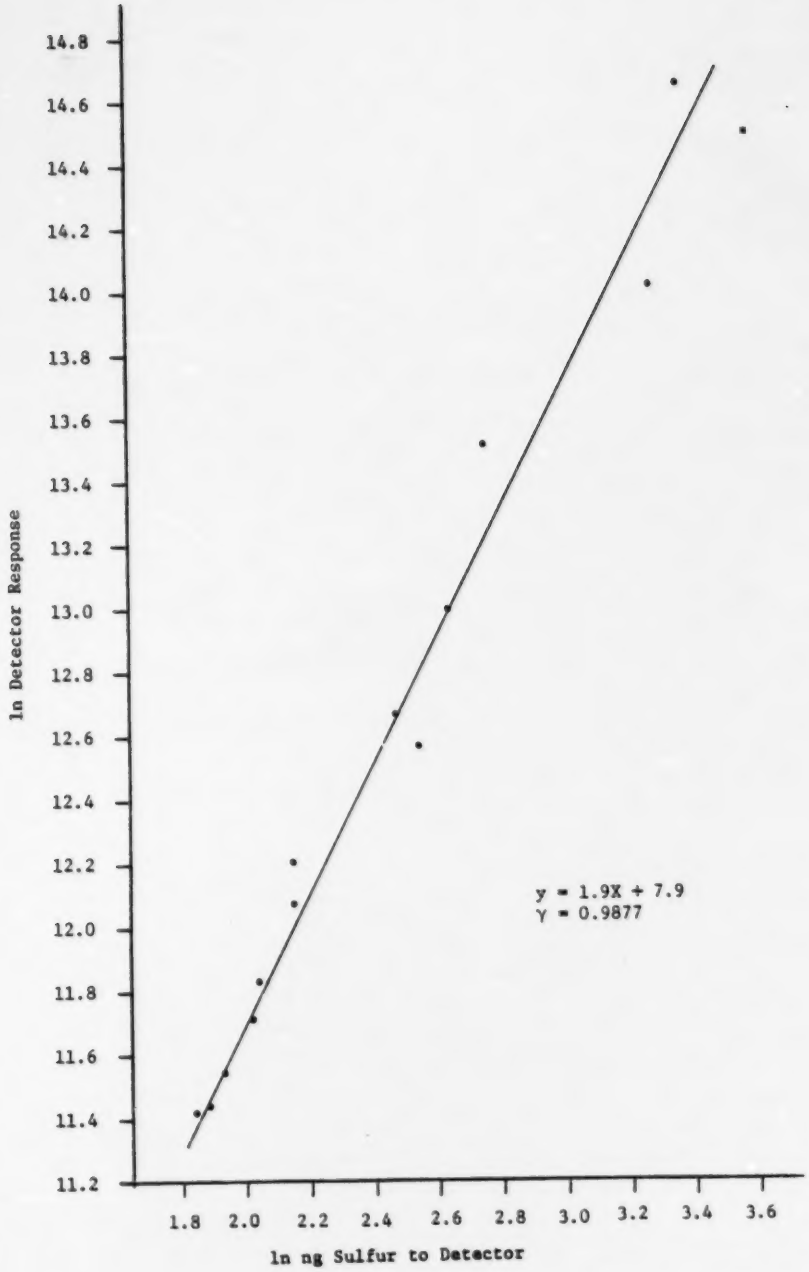


Figure D-16. Carbon disulfide (CS_2) calibration curve.

Species	STD #1	STD #2	STD #3
CH_4	0.62%	4.04%	2.10%
CO	24.7%	10.0%	40.08%

Figures D-17 through D-20 show the calibration curves that were obtained.

D.5.3 Light Hydrocarbons

C_1-C_6 hydrocarbons were analyzed on site using the following instrument parameters:

Instrument:	Tracor Model 560 FID-GC
Column:	6 ft. x 1/8 inch OD stainless steel, 80/100 mesh Porapak Q
Carrier:	Nitrogen at 30 mL/min.
Detector Temperature:	300°C
Oven Program:	50°C for 2 minutes; 10°C/min. to 200°C; 200°C until baseline reestablished

Calibration curves were obtained using certified gas mixtures of C_1-C_6 paraffins and C_2-C_6 olefins. Response factors for methane, ethane, and ethylene were determined individually. Average response factors for the paraffins and corresponding olefins for C_3-C_6 hydrocarbons was used. Calibration curves are presented in Figure D-21.

D.6.0 ORGANIC ANALYSES

Preliminary analyses of the samples were done using established methods (Ref. D-8) with modifications. These modifications are included in the following descriptions of the analytical methods. Detailed analyses were done using a computer assisted gas chromatography - mass spectrometry system

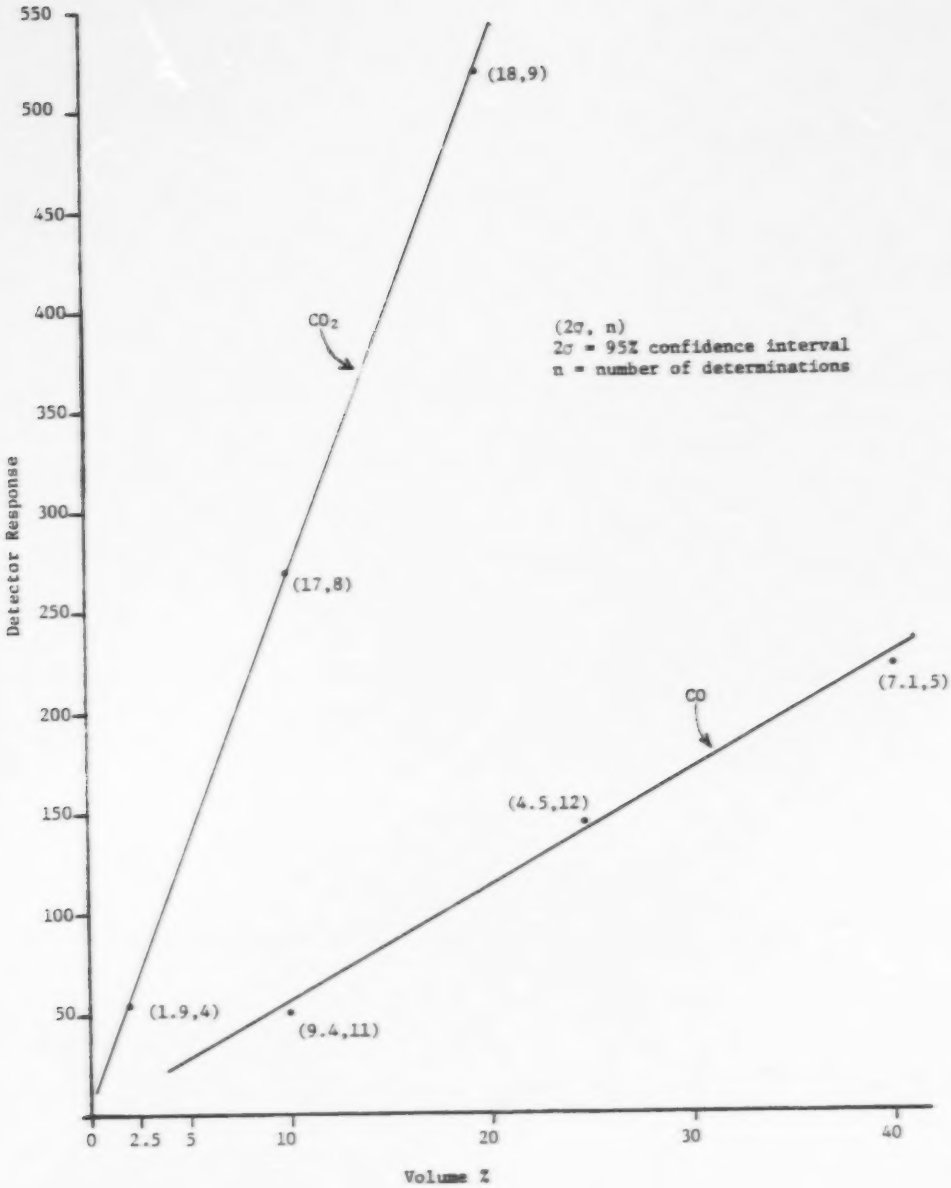


Figure D-17. Calibration curves for carbon dioxide (CO_2) and carbon monoxide (CO).

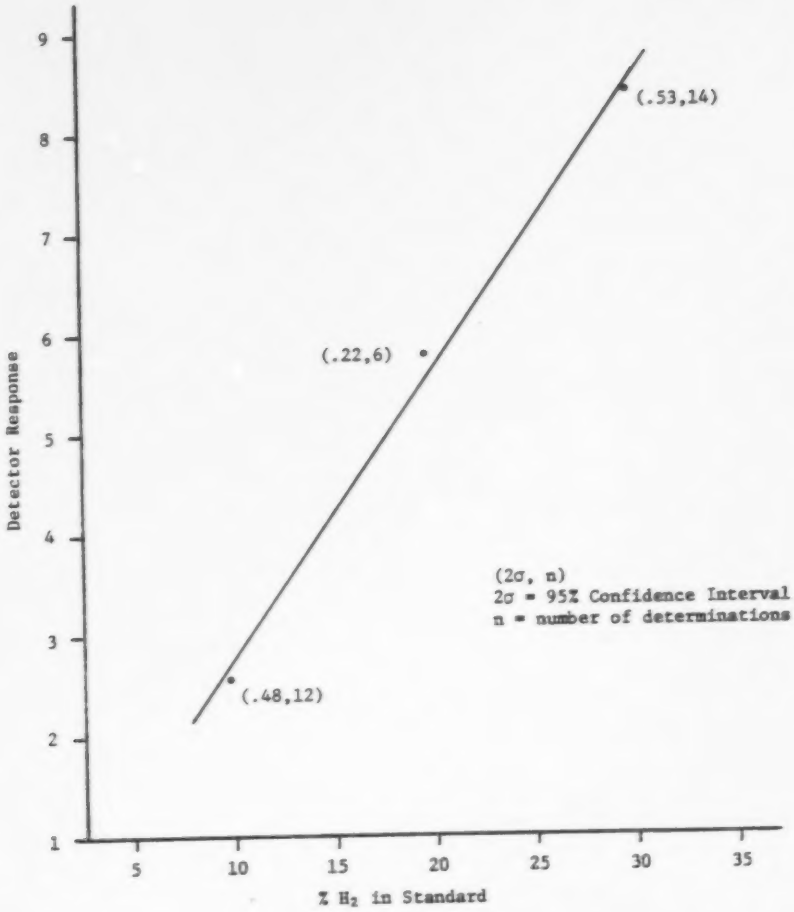


Figure D-18. Hydrogen calibration curve.

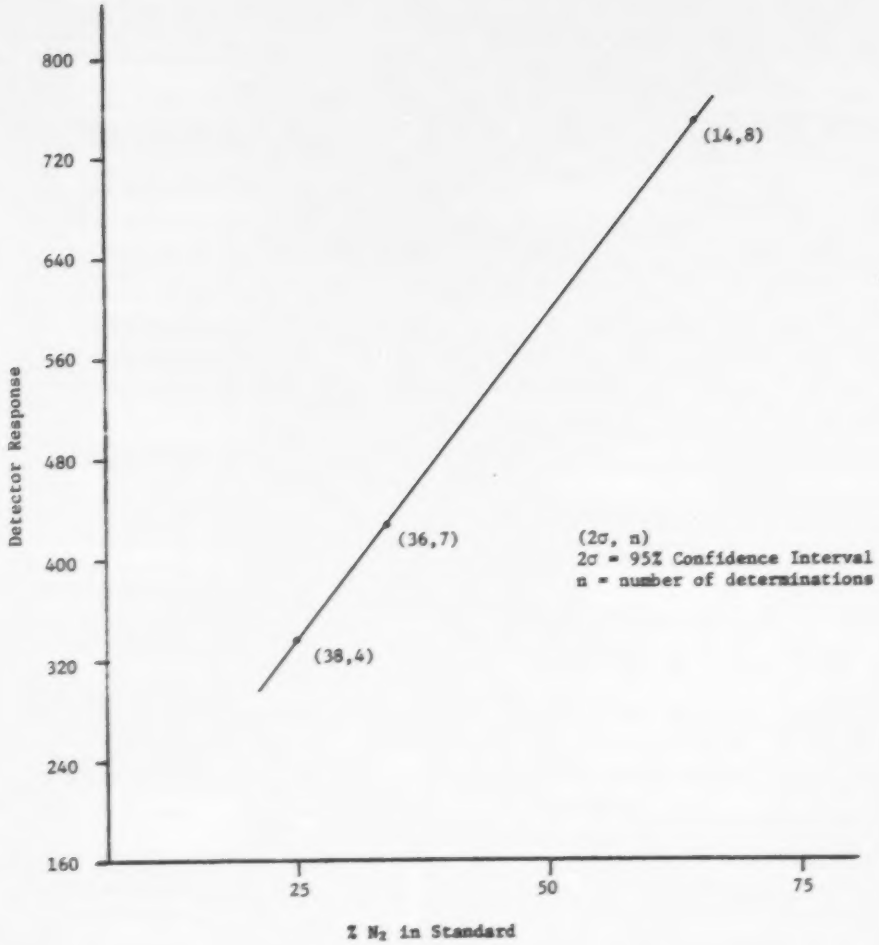


Figure D-19. Nitrogen calibration curve.

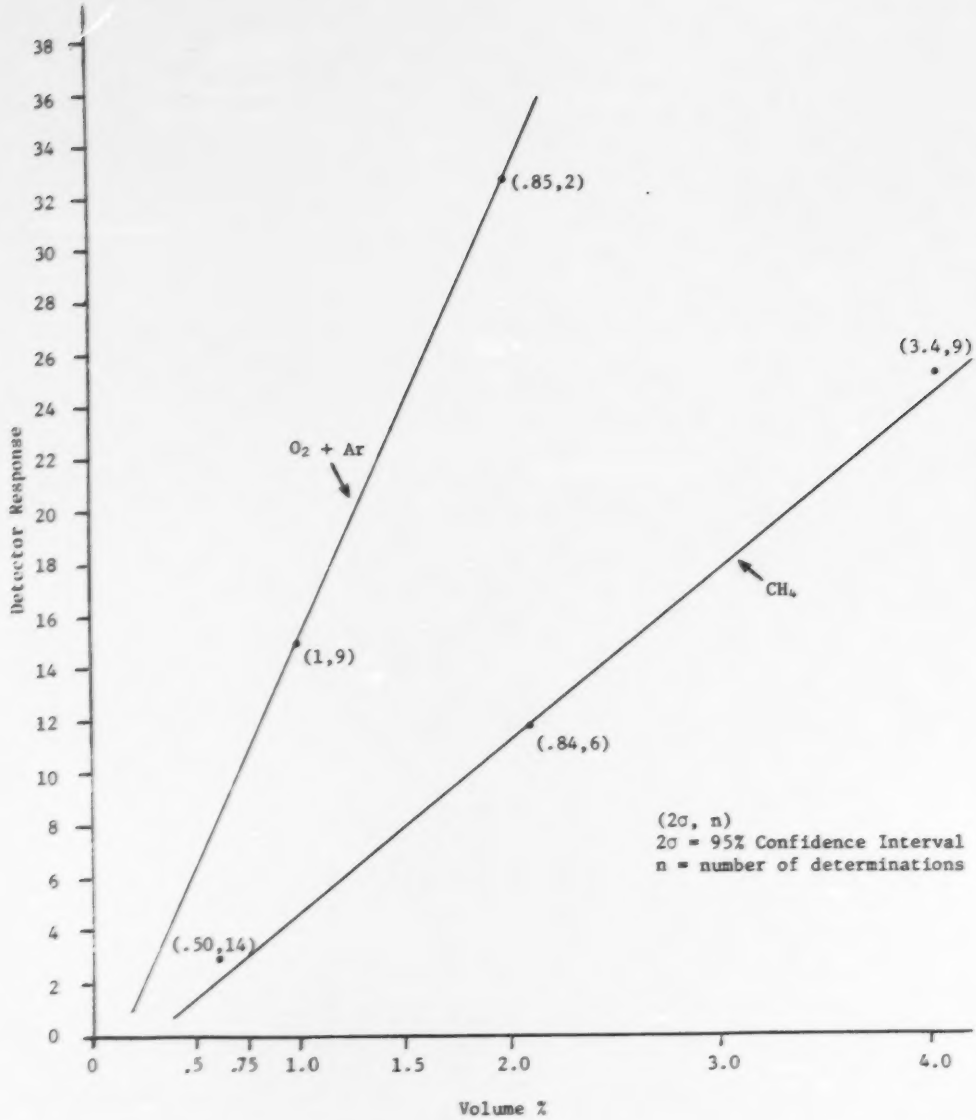


Figure D-20. Calibration curves for methane (CH_4) and oxygen (O_2 + Ar).

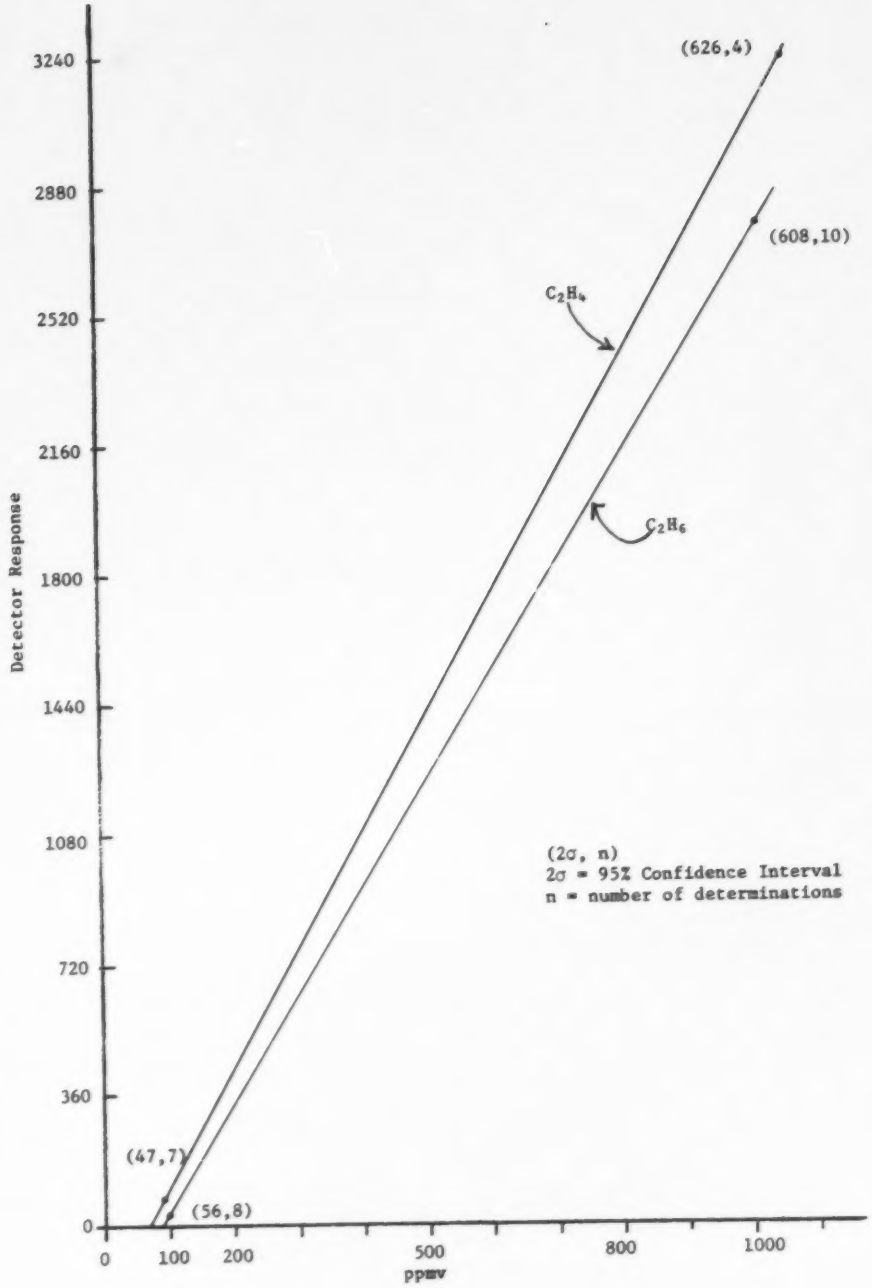


Figure D-21. Ethane (C_2H_6) and ethylene (C_2H_4) calibration curves.

(GC-MS). GC-MS analysis was done after sample screening by gas chromatograph (GC) using a selective detector in nitrogen-, sulfur-, and halogen-specific modes and after screening for PCB's. These GC analyses yielded data pertaining to organic compounds and compound classes which contain specific heteroatoms at very low additional cost to the comprehensive analysis.

D.6.1 Extractions

Aliquots of the aqueous samples were extracted at both pH=2 and pH=12. Serial extractions using methylene chloride followed by diethyl ether were done at each pH to obtain a wider range of extractable organics than extraction with a single solvent would have yielded. After extraction, the methylene chloride and ether fractions were combined to yield one extract for each sample. The extracts were concentrated using Kuderna-Danish concentrators equipped with 3-ball Snyder columns.

Aliquots of solid samples were extracted in Soxhlet extractors for 24 hours with methylene chloride followed by 24 hours with ether. After extraction, the 2 fractions were combined to yield one extract for each sample.

The use of diethyl ether to extract the aqueous and solid samples was an addition to the cited methods (Ref. D-8).

D.6.2 Total Chromatographable Organics Analysis (TCO)

TCO analysis is a means of quantitating organics with boiling points in the range of 100°C to 300°C using gas chromatography. Quantitation was performed by comparing sample chromatograms to an n-C_7 - C_{17} boiling point standard and an n-C_8, C_{12}, C_{16} quantitative standard. The quantitative standard was analyzed at concentrations approximating sample concentrations. The following conditions were used:

Instrument:	Tracor Model 560 FID-GC
Column:	3 m x 2 mm ID glass, 10% OV-101 on 60/80 mesh Supelcoport
Carrier:	Nitrogen at 40 mL/min
Injector:	265°C
Detector:	300°C
Oven Program:	50°C for 5 min; 20°C/min to 250°C; 250°C hold until baseline reestablished

Chromatograms were recorded and integrated with a Hewlett-Packard 3390 integrator. Solvent blanks were analyzed for all samples and subtracted from sample values.

D.6.3 Gravimetric Analysis (GRAV)

GRAV analysis is a means of quantitating the non-volatile portion of a sample extract. Theoretically, this includes all compounds with a boiling point greater than 300°C. GRAV analyses were done on initial extracts and on liquid chromatographic (LC) fractions. A Mettler H-80 4-place analytical balance was used for all weighings.

GRAV analyses on the unfractionated extracts and LC fractions were done by taking volumetric aliquots of the concentrated extracts or LC fractions The GRAV aliquots were placed in tared beakers and allowed to evaporate to dryness at room temperature in a desiccator. If less than 10 mg or material was present, additional aliquots were added until approximately 10 mg of GRAV material was present. In some cases for the LC fractions, this was not done due to low total masses in the fractions. Weighings were done at minimum 24-hour intervals until a maximum variation of $\pm$ 0.1 mg was observed. Solvent and LC fraction blanks were analyzed along with the samples and subtracted from sample values.

D.6.4 Gas Chromatographic Analysis - Benzene, Toluene, and Xylenes

Benzene, toluene, and xylene samples were taken using 2-section glass tubes packed with activated charcoal. After sampling, the tubes were refrigerated until they could be extracted. Extraction was carried out by separate elution of the front and back sections of charcoal with carbon disulfide for 30 minutes with shaking. Analyses of the front and back sections of charcoal extracts were done separately using the following instrument parameters:

Instrument:	Tracor Model 560 FID-GC
Column:	1.8 m x 2 mm ID glass, 5% SP-1200/1.75% Bentone 34 on 100/120 mesh Supelcoport
Carrier:	Nitrogen at 25 mL/min
Injector Temperature:	275°C
Detector Temperature:	300°C
Oven Program:	60°C for 3 min; 10°C/min to 120°C

Calibration was performed by analyzing known quantities of benzene, toluene, and xylenes and establishing response factors for the compounds.

D.6.5 Gas Chromatographic Analysis - Hall Detector

Gas chromatography was performed using a Hall 700-A electrolytic conductivity detector (HECD). The HECD may be used in either the halogen, sulfur, or nitrogen specific mode. Three analyses were performed on each extract, one in each of the the three detector modes. This provided measurements analogous to TCO values for classes of organic compounds containing specific heteroatoms. The analytical parameters were:

Instrument:	Tracor Model 560 HECD-GC
Columns:	3 m x 2 mm ID glass, 10% OV-101 on 60/80 mmesh Supelcoport (halogen and sulfur modes); 10% Apiezon L/2% KOH on 80/100 mesh Chromosorb W AW (nitrogen mode).
Carrier:	Helium at 40 mL/min
Oven Program:	50°C for 5 min; 20°C/min to 250°C; 250°C hold until baseline reestablished.
Injector Temperature:	265°C
Detector Temperature:	265°C
Standards:	Halogen mode - hexachlorobenzene Sulfur mode - ethyl parathion Nitrogen mode - pyridine

Samples were solvent exchanged with cyclopentane prior to analysis. Chromatograms were plotted and integrated with a Hewlett-Packard Model 3388 data processor. Standards were analyzed to provide boiling point references and concentration correlations. Solvent blanks were analyzed with the samples and subtracted from sample values.

D.6.6 Gas Chromatographic Analysis - Electron Capture Detector

Extracts were analyzed for PCBs by electron capture detector using the following parameters:

Instrument:	Tracor Model 560 GC equipped with Ni^{63} Electron Capture Detector
Column:	6 ft x 1/8 in. ID glass, 1.5% SP-2401 on 100/120 Supelcoport
Carrier:	Argon/Methane at 30 mL/min
Make-up:	Argon/Methane at 30 mL/min

Injector Temperature:	225°C
Detector Temperature:	350°C
Oven Program:	180°C for 5 min; 8°C/min. to 210°C; 210°C for 25 min.

Samples were solvent exchanged with cyclopentane prior to analysis. Chromatograms were plotted and integrated with a Hewlett-Packard Model 3388 data processor. Standards were analyzed to provide boiling point references and concentration correlations. Solvent blanks were analyzed with the samples and subtracted from sample values.

D.6.7 Mass Spectrometric Analysis

Composited extracts for each of seven samples were analyzed using gas chromatography - mass spectrometry (GC-MS). The samples were analyzed for the base-neutral and acid extractable EPA Priority Pollutants given in Table D-1 using a computer assisted search. This technique searches for specific compounds based on the appearance of three characteristic fragment ions within a known relative retention time window. Quantitation was done by response factor comparison to a known amount of d_{10}-anthracene.

Samples were analyzed by GC-MS using the following parameters:

Instrument:	Hewlett-Packard 5985 GC-MS system
Column:	30 meter SE-54 fused silica capillary
Carrier:	Hydrogen at 35 cm/sec
Injector Temperature:	250°C
Oven Program:	25°C for 3 min; 16°C/min to 60°C and 6°C/min to 300°C
Ionizing Voltage:	70 eV

TABLE D-1. BASE/NEUTRAL AND ACID EXTRACTABLE PRIORITY POLLUTANTS ANALYZED BY GC-MS

Base/Neutral Extractable		Acid Extractable	
Compound	m/e	Compound	m/e
1. 1,3-Dichlorobenzene	146	1. 2-Chlorophenol	128
2. 1,4-Dichlorobenzene	146	2. 2-Nitrophenol	139
3. Hexachloroethane	117	3. Phenol	94
4. 1,2-Dichlorobenzene	146	4. 2,4-Dimethylphenol	12
5. Bis(2-Chloroethyl) ether	93	4. 2,4-Dichlorophneol	162
6. Bis(2-Chloroisopropyl) ether	121	6. 2,4,6-Trichlorophenol	196
7. Nitrobenzene	77	7. p-Chloro-m-cresol	142
8. N-Nitrosodimethylamine	74	8. 2,4-Dinitrophenol	184
9. N-Nitrosodi-n-propylamine	130	9. 4,6-Dinitro-o-cresol	198
10. Hexachlorobutadiene	225	10. Pentachlorophenol	266
11. Isophorone	82	11. 4-Nitrophenol	139
12. 1,2,4-Trichlorobenzene	180	12. 2,2-Difluorobiphenyl	190
13. Bis(2-Chloroethoxy) methane	93		
14. Naphthalene	128		
15. Hexachlorocyclopentadiene	237		
16. 2-Chloronaphthalene	162		
17. Acenaphthylene	152		
18. Acenaphthene	154		
19. Dimethyl phthalate	163		
20. 2,6-Dinitrotoluene	63		
21. 4-Chlorophenyl phenyl ether	204		
22. Fluorene	166		
23. 2,4-Dinitrotoluene	63		
24. Diethyl phthalate	149		
25. N-Nitrosodiphenylamine	169		
26. 1,2-Diphenyl Hydrazine	77		
27. Hexachlorobenzene	284		
28. 4-Bromophenyl phenyl ether	248		
29. Phenanthrene	178		
30. Anthracene	178		
31. Di-n-butyl phthalate	149		
32. Fluoranthene	202		
33. Pyrene	202		
34. Benzidine	184		
35. Butyl benzyl phthalate	149		
36. Bis(2-Ethylhexyl) phthalate	149		
37. ICDD	322		
38. Chrysene	228		
39. Benz(a)anthracene	228		

(Continued)

TABLE D-1. (Continued)

Base/Neutral Extractable		Acid Extractable	
Compound	m/e	Compound	m/e
40. 3,3-Dichlorobenzidine	252		
41. Di-n-octyl phthalate	149		
42. Benzo(b)fluoranthene	252		
43. Benzo(k)fluoranthene	252		
44. Benzo(a)pyrene	252		
45. Indeno (1,2,3-c,d)pyrene	276		
46. Benzo(a,h)anthracene	278		
47. Benzo(g,h,i)perylene	276		

[1]ratio of mass to electron charge

D.6.8 Liquid Chromatographic Separation (LC)

The LC separation gives a fractionation of the sample extract into compound classes based on polarity. This is not a high resolution technique, and compound classes may overlap in individual fractions. However, with adequate care, reproducible, predictable separations can be achieved. Table D-2 presents the organic compound classes as separated into the seven LC fractions.

Samples were prepared for fractionation using recommended procedures (Ref. D-8). All extracts were solvent exchanged from methylene chloride/diethyl ether to cyclopentane over 200 mg silica gel. Using the recommended solvent exchange results in a solvent mixture containing less than 5% methylene chloride/ether. This is sufficiently low not to alter the polarity of the elution series. The exchanged extract and 200 mg silica gel were transferred to the LC column and eluted with a series of 7 solvent mixtures on the basis of increasing polarity. The LC column parameters were:

Column:	200 mm x 10.5 mm ID glass with Teflon stopcock, glass solvent reservoir; water-jacketed, outlet water temperature 20°C.
Absorbent:	Silica gel, 60-200 mesh, Davidson, Grade 950. Soxhlet extracted serially with methanol, methylene chloride, and pentane, activated at 110°C for 2 hours. Slurry packed in n-pentane.
Drying Agent:	Sodium sulfate, reagent grade, fired at 500°C for 4 hours. 3 g added to top of column.
Elution Series:	Pentane; methylene chloride/pentane 1:4; methylene chloride/pentane 1:1; methylene chloride; methanol/methylene chloride 1:19; methanol/methylene chloride 1:4; methanol/methylene chloride 1:1. Pentane fraction = 25 mL, all others = 10 mL.

TABLE D-2. COMPOUND CLASSES SEPARATION USING LIQUID CHROMATOGRAPHY TECHNIQUE†

Category (Subcategory)	Most Probable LC Fraction*	Category (Subcategory)	Most Probable LC Fraction*
Aliphatic hydrocarbons	1	Phenols	6
(Alkanes)	1	(Alkyl, etc.)	6
(Alkenes)	1	(Halogenated phenols)	6
(Alkynes)	1	(Nitrophenols)	6
Halogenated aliphatics	1,2	Esters	6
(Saturated)	1,2	(Phthalates)	6
(Unsaturated)	1,2	Ketones	6
Aromatic hydrocarbons	2,3	Amines	6
(Benzenes)	2,3	(Primary, secondary, tertiary)	6
Halogenated aromatic hydrocarbons	2,3	(Hydraxines, azo compounds)	6
Nitro aromatic hydrocarbons	4,5	(Nitrosoamines)	6
Fused alternate, nonalternate hydrocarbons	2,3	Heterocyclic nitrogen compounds	
MW < 216 (methyl pyrene)	2,3	(Indoles, carbazoles)	4
MW > 216	2,3	(Quinolines, soridines)	6
Ethers	4	Alkyl sulfur compounds	6
(Halogenated ethers)	4	(Mercaptans)	6
Epoxides	4	(Sulfides, disulfides)	6
Aldehydes	4	Heterocyclic sulfur compounds	
Heterocyclic oxygen compounds	4	(Benzothiophenes)	4
Nitriles	4	Sulfonic acids, sulfoxides	7
(Aliphatic)	4	Amides	6
(Aromatic)	4	Carboxylic acids	6,7
Alcohols	6	Silicones	2,3,4
(Primary, secondary, tertiary)	6	Phosphates	5,6,7
(Glycols)	6		

*Possible assignments. Fractions 4-5, 5-6, 6-7 generally overlap to a considerable extent. Also, additional components of a particular molecule may cause it to elute in an LC fraction other than that expected. For example, a short-chain ester would probably elute in LC fraction 5 or 6, whereas a long-chain ester would elute in Fractions 3 or 4.

†Reference D-8.

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D-6 American Society for Testing and Materials, 1974 Annual Book of ASTM Standards Part 31: Water, Philadelphia, Pennsylvania, 1977.

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D-8 Lentzen, D.E., D.E. Waggoner, E.D. Estes, and W.F. Gutknecht, IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition), NTIS No. Pb-293 795, Research Triangle Institute, Research Triangle Park, North Carolina, October 1978. (EPA-600/7-78-201)

D-9 U.S. EPA, Methods for Chemical Analysis of Water and Wastewater, EPA 600/4-79 020, March 1979.

D-10 American Society for Testing and Materials, 1977 Annual Book of ASTM Standards Part 26, Gaseous Fuels: Coal and Coke: Atmospheric Analysis, Philadelphia, Pennsylvania, 1977.

D-11 Resource Conservation and Recovery Act, Public Law 95-580.

APPENDIX E

PROCESS DATA

Appendix E presents process data for the Foster Wheeler/Stoic gasifier at UMD. The gasifier hourly log from February 23, 1981 through March 3, 1981 is presented in Table E-1. Table E-2 presents the hourly log for the boilers. The flow rate, molecular weight, and moisture content of the product and combustion emission streams are presented in Table E-3.

Figures E-1 through E-8 present the results of continuous SO_x and NO_x montoring by UMD personnel for the period 2/24/81 through 3/3/81.

NOTES ON DULUTH GASIFIER HOURLY LOG

1. CALCULATION OF FLOW RATES

Steam/FT21A, Steam/FT21B read the same flow; readings are high and low range meters, respectively, and are a measure of the jacket steam flow to the blast air.

For FT21A, divide the reading by 100, determine the square root, and multiply by 4,000 to obtain indicated steam flow in lbs/hr.

For FT21B, divide the reading by 100, determine the square root, multiply by 971 to obtain indicated steam flow in lbs/hr.

AIR TO VEN. (air to vent). Multiply reading by 970 (blast air flow) to obtain flow rate in lbs/hr.

Water TO Jack. (water to jacket). This value is the feed water flow rate to the gasifier steam jacket in gal/min.

2. TAR

Tank Level value is percent of tank level where 0-100% = 0-32", 0" = 1 ft. in tank or 0% = 1 ft. in tank.

3. WATER

Jacket FEED. This value is the cumulative quantity of feed water to the gasifier jacket. Subtract consecutive values to obtain gallons added during a specific time period.

4. COAL

COAL. This is the cumulative number of dumps. Subtract consecutive values, multiply by the coal scale calibration factor, and on all sheets (except 2-24-81 TEST RUN 1 sheet) multiply by 0.94 to obtain lbs of coal.

5. ELECTRIC

ELECTRIC. Multiply difference by 120 to obtain KWH (cumulative).

6. TAR

TAR. Cumulative amount of tar pumped in gallons.

7. WATER

WATER. This is the total (cumulative) water to gasifier building. Multiply the difference by 100 to obtain gallons.

8. AIR FLOW

AIR FLOW. Multiply the difference by 10 to obtain cumulative lbs air.

9. BOILER FEEDWATER TO JACKET

BFW TO JACK. (This flow totalizer reading did not change, instrument was not working.)

10. HEAT TRACE

HEAT TRACE. Multiply difference by 100 to obtain cumulative lbs of steam.

11. ESP VOLTAGE

ESP LOAD VOLTS. Multiply by 1000 to obtain ESP voltage.

12. ESP CURRENT

ESP LOAD CUR. Value is in milliamps.

BOILER HOURLY LOG

1. GAS PRESS. Gas Pressure is in inches of H_2O.
2. STEAM. Readings times 35 equals lbs of steam/hr.
3. COND. Difference in readings times 1000 equals lbs of boiler feedwater.
4. GAS. Difference in readings times 12.4 equals lbs of gas (fuel).
5. CONDENSATE. Same as COND. above.
6. (OIL) TAR. Difference in readings equals gallons.

WET ASH TOTALS

0800 hrs, 2-24-81 to 1900 hrs, 2-24-81	4144 lbs
1900 hrs, 2-24-81 to 1200 hrs, 2-25-81	6720 lbs
1200 hrs, 2-25-81 to 1050 hrs, 2-27-81	7460 lbs

CYCLONE DUST TOTALS

0800 hrs, 2-24-81 to 1900 hrs, 2-24-81	9 lbs
1900 hrs, 2-24-81 to 1200 hrs, 2-25-81	14 lbs
1200 hrs, 2-26-81 to 1500 hrs, 2-27-81	54 lbs

TABLE E-1. UMD GASIFIER HOURLY LOG

DULUTH GASIFIER HOURLY LOG

Date 2/23/81	TEMPERATURE °F									PRESSURE " H_2O						FLOW RATE				TAR		Water	COAL	COMMENTS
	1	2	3	4	5	6	7	8	9	TOP GAS	BOT GAS	Shaft	Air TO VEN.	Mix-ed GAS	Steam Jack	Steam TO TBM	Steam TEMP	AIR TO VEN.	Water TO Jack	Tank Level	PUMP Status On/Off	Jacket FEED		
100	194	354	111	918	345	215	127	121	131	24	30	32	34	24	34	0.6	199	4.9	4.4	2	OFF	125743	305776	Grate A-6.3 BST 122
200	201	341	111	921	342	234	126	122	134	24	30	32	34	24	36	1.0	208	4.9	1.0	4	OFF	125871	305899	
300	206	339	111	924	344	204	127	119	133	24	30	32	34	24	36	0.7	153	4.9	1.6	8	OFF	125989	305918	
400	207	392	111	870	451	220	125	122	133	24	26	30	31	24	34	0.9	19.5	5.0	3.4	10	OFF	126164	305959	
500	199	442	110	884	478	198	124	123	134	24	26	30	30	24	32	0.8	20.7	4.9	0.5	12	OFF	126282	305981	BST to 124
600	193	391	110	855	378	215	128	124	133	24	29	32	34	24	34	0.2	10.0	4.8	3.0	14	OFF	126442	306007	
700	195	426	110	878	437	207	125	120	136	24	27	30	32	24	34	1.6	21.5	4.8	1.8	14	ON	126615	306034	
800	192	430	110	885	452	189	126	122	137	23	27	30	32	24	32	1.4	28.3	4.9	0	2	OFF	126720	306057	
900	180	423	109	842	470	189	118	125	136	23	23	24	24	24	26	-	28	1.0	0	4	OFF	126889	306069	Data taken at 9:30
1000	180	399	109	826	368	157	121	125	138	24	26	28	28	24	30	1.0	23.1	2.9	0	4	OFF	126921	306082	
1100	183	350	111	826	338	222	130	124	131	24	24	26	30	-	32	1.5	32.5	4.1	0	6	OFF	127028	306098	
1200	188	358	112	829	352	226	131	123	136	24	27	30	30	24	34	0.7	19.7	4.3	3.8	9	OFF	127157	306120	
1300	188	392	112	851	411	201	133	123	137	24	26	30	30	25	32	0.2	10.6	4.5	4.2	10	OFF	127261	306141	
1400	188	425	109	876	474	204	129	121	137	24	26	30	30	24	32	1.4	27.6	5.1	0	13	OFF	127400	306167	
1500	189	370	111	854	395	209	131	122	135	24	28	32	32	24	34	0.5	15.2	5.2	2.4	14	OFF	127546	306194	Grate A-6.0
1600	191	398	111	865	404	215	132	113	138	24	28	31	32	24	34	0.9	20.7	5.0	2.1	16	OFF	127685	306221	Grate A-6.4
1700	190	396	111	865	405	206	129	116	133	24	28	31	32	24	34	0.6	16.7	5.1	1.8	18	OFF	127847	306245	BST 130 °F
1800	188	396	112	870	428	190	127	118	135	24	28	31	32	24	34	1.0	21.2	5.0	5.9	2	OFF	127988	306275	Grate A-6.2
1900	192	361	113	858	369	228	127	119	138	24	28	31	32	24	33	1.1	23.5	5.1	6.6	5	OFF	128122	306299	
2000	195	392	113	874	408	215	125	120	136	24	28	32	32	24	34	1.3	26.9	4.9	1.1	7	OFF	128274	306324	
2100	196	400	114	877	416	208	123	120	135	24	28	31	32	24	34	1.3	26.9	4.8	4.1	10	OFF	128418	306359	
2200	198	405	114	881	418	232	120	121	137	24	28	31	32	24	35	2.2	46.6	4.8	1.0	12	OFF	128557	306380	Grate A-6.8 at 10:15
2300	202	409	114	884	421	231	119	121	136	24	28	31	32	24	35	2.1	39.5	4.8	1.4	16	OFF	128676	306401	
2400	202	411	114	887	421	217	117	114	135	24	28	31	32	24	34	1.7	32.6	4.8	1.0	8	OFF	128795	306426	

	1200 HRS	2400 HRS		1200 HRS	2400 HRS
ELECTRIC	1424	1430	ESP LOAD Volts	36	36
TAR	299589	299809	ESP LOAD Cur	60	60
WATER	59272	59.259	ESP SPARK Rate	0	0
AIR FLOW	546228	551677			
BFW TO JACK	9999391	9999391			
HEAT TRACE	2541	2550			

COAL SCALE CALIBRATION 189 lbs/dump

TEMPERATURES
1 T81 TOP GAS AFTER ESP
2 MIXED GAS, BOILER 1
3 MIXED GAS, BOILER 2
4 T64 BOTTOM GAS
5 T66 MIXED GAS
6 T65 TOP GAS BEFORE ESP
7 T68 BLOWER AIR TEMP.
8 T69 ASH PAN
9 T70 BST

GAS ANALYSIS

Time										
H_2										
$AR-O_2$										
N_2										
CO										
CH_4										
CO_2										
H_2O										

1/81

(Continued)

TABLE E-1. (Continued)

DULUTH GASIFIER TEST Run 1

Date 2/24/81	TEMPERATURE °F 1	2	3	4	5	6	7	8	9	PRESSURE " H_2O TOP GAS	BOT GAS	Bleed	AIR TO VEN	Ash-ed GAS	Bleed Ash	FLOW RATE Bleed PTOB	Bleed FTOB	AIR TO VEN	Water TO Jack	TAR Tank Level	PUMP Status On/Off	Water JACKET FEED	COAL	COMMENTS
900	196	378	112	854	358	218	117	117	124	24	30	33	34	29	36	2.2	382	4.7	194	0	OFF	129908	2151	Start Test Run
930	188	361	112	852	350	216	118	118	125	24	30	33	35	29	36	2.3	423	4.7	2.14	0	OFF	129968	—	
900	189	377	112	865	390	207	119	118	126	24	30	32	33	29	34	2.0	378	4.7	2.01	2	OFF	129935	2178	[illegible]
930	199	404	111	882	442	198	118	118	126	24	27	30	32	29	33	2.0	351	4.7	2.16	3	OFF	129987	—	Ash pan level 50
1000	188	390	111	860	372	212	121	119	126	24	27	28	34	29	36	1.6	29.6	4.7	0.93	4	OFF	130045	2201	
1030	187	387	111	866	389	200	122	118	134	24	28	32	39	29	39	1.7	33.5	4.7	19	6	OFF	130115	—	Wet ash Totals 8:00 - 19:00
1100	197	383	110	866	388	204	123	119	135	24	28	32	34	29	36	2.1	38.8	4.9	4.23	7	OFF	130177	2230	Heating Plant side 2790 lbs
1130	197	412	110	886	453	196	122	118	135	24	26	30	37	29	33	1.6	30.5	4.8	1.35	8	OFF	130237	—	Garage side 1354 lbs
1200	189	420	109	887	456	192	124	118	135	24	26	30	32	29	34	1.5	29.2	4.8	.32	10	OFF	130309	2252	Moisture in ash - 37%
1230	188	412	109	877	416	209	126	119	135	24	28	31	32	29	34	1.4	29.9	4.6	4.12	11	OFF	130375	—	
1300	187	386	108	859	366	207	128	119	135	24	30	33	35	29	35	1.6	29.9	4.9	.63	12	OFF	130425	2279	Cyclone Dust 8:00-19:00 - 9 lbs
1330	189	394	108	876	416	218	126	119	135	24	28	32	33	29	33	1.6	28.3	4.9	.99	13	OFF	130497	—	
1400	189	407	107	879	424	209	129	119	135	24	28	32	33	29	34	1.8	26.3	4.9	3.59	12	OFF	130560	2306	Coal Temperature 53°F
1430	190	420	107	886	446	209	128	119	135	24	27	31	32	29	33	1.5	24.5	4.9	.84	13	OFF	130629	—	
1500	191	416	106	886	447	205	126	119	135	24	27	30	32	29	32	1.3	25.3	4.9	.85	16	OFF	130692	2329	Boiler Data 8:15 - 19:15
1530	189	432	106	892	461	191	127	119	135	24	26	30	32	29	33	1.4	26.6	4.9	2.29	17	OFF	130757	—	Steam - 187590 lbs
1600	196	444	105	895	461	185	126	119	136	24	26	30	32	29	32	1.3	25.7	4.9	1.36	18	OFF	130816	2352	Feed water - 175100 lbs
1630	194	448	105	897	467	198	125	119	136	24	26	30	32	29	32	1.1	22.7	4.9	2.95	19	OFF	130886	—	
1700	196	387	104	867	460	215	125	119	135	24	30	33	39	29	34	1.4	28.8	4.8	1.42	20	OFF	130955	2379	Estimated Gas Flow 8:15 - 19:15
1730	189	369	104	865	352	221	124	119	136	24	30	33	34	29	36	1.6	29.1	4.9	1.37	21	OFF	131011	—	84,700 lbs
1800	195	356	104	863	350	225	128	119	136	24	30	39	35	29	36	1.8	34.3	4.9	1.38	22	OFF	131082	2405	
1830	198	374	102	881	409	226	122	119	140	24	26	30	31	29	33	1.9	36.9	4.9	1.15	22	OFF	131164	—	
1900	196	419	103	896	462	200	122	118	137	24	26	30	31	29	33	1.8	34.5	4.9	2.79	—	OFF	131248	2430	Run stopped at 19:00 Bad fire Bed
1930																								

	800 HRS.	8900 HRS.		800 HRS.	8900 HRS.
ELECTRIC	1434	1439	ESP LOAD Volts	39	36
TAR	300043	308264	ESP LOAD Cur	60	60
WATER	59356	59948	ESP SPARK Rate	0	0
AIR FLOW	555365	560388	Barometer	28.5	
BFW TO JACK.	9998891	9999391			
HEAT TRACE	2556	2565			

COAL SCALE CALIBRATION 103 lbs/dump

TEMPERATURES

1 T61 TOP GAS AFTER ESP
2 MIXED GAS, BOILER 1
3 MIXED GAS, BOILER 2
4 T64 BOTTOM GAS
5 T66 MIXED GAS
6 T65 TOP GAS BEFORE ESP
7 T68 BLOWER AIR TEMP
8 T69 ASH PAN
9 T70 BST

Tar pumped until 19:40

GAS ANALYSIS

Time	12:40	13:30
H_2	19.2	-
$AR-O_2$	-	-
N_2	47.02	-
CO	33.4	-
CH_4	1.66	-
CO_2	3.66	-
H_2O		12.1

1/81

(Continued)

TABLE E-1. (Continued)

DULUTH GASIFIER HOURLY LOG

Date 2/24 81	TEMPERATURE °F 1	2	3	4	5	6	7	8	9	PRESSURE " H_2O TOP GAS	BOT GAS	Blast	AIR TO VEN	Mixed GAS	Steam Jack.	FLOW RATE Steam FT3/H	Steam FT3/H	AIR TO VEN.	Water TO Jack	TAR Tank Level	PUMP Status On/Off	Water Jacket FEED	COAL	COMMENTS
100	198	408	114	885	415	182	115	117	138	24	28	30	32	24	34	0.7	22.4	4.6	2.4	8	OFF	129919	306464	Grate A-6.5 BST 134
200	193	354	116	858	345	224	116	120	134	24	28	32	34	24	36	1.4	20.7	4.8	1.4	6	OFF	129947	306496	
300	202	356	116	862	368	235	117	119	136	24	29	32	34	24	36	2.7	48.2	4.8	1.0	8	OFF	129959	306521	
400	208	407	116	881	435	210	117	111	136	24	28	31	32	24	36	1.9	28.5	4.8	3.0	10	OFF	129985	306550	
500	199	428	115	887	462	185	118	112	135	24	26	30	31	24	34	1.9	35.1	4.8	1.8	12	OFF	129906	306577	Grate A-6.0
600	191	412	114	875	421	204	117	116	134	24	28	31	32	24	34	1.4	28.8	4.8	–	14	OFF	129997	306605	
700	188	410	113	879	418	199	116	117	135	24	28	30	32	24	34	1.5	32.0	4.7	1.4	16	OFF	129682	306634	
800	185	389	112	856	363	209	116	117	134	24	29	32	32	24	36	2.1	36.3	4.7	1.8	2	ON	129795	306660	
900	189	376	112	865	388	206	118	118	134	24	28	32	32	24	36	1.6	29.1	4.7	2.6	2	OFF	129924	306692	
1000	188	390	111	860	372	212	121	119	136	24	27	33	34	24	36	2.2	35.2	4.7	3.5	4	OFF	130045	306718	
1100	187	384	110	867	388	202	123	119	135	24	28	32	32	24	34	1.6	29.6	4.8	3.4	6	OFF	130166	306744	
1200	189	411	109	880	444	215	124	119	135	24	26	30	32	24	34	1.6	29.4	4.8	0	9	OFF	130308	306774	
1300	187	383	108	859	364	209	128	119	135	24	30	33	34	24	36	0.2	31.2	4.8	3.2	12	OFF	130433	306800	
1400	189	406	107	879	423	208	128	119	135	24	28	30	32	24	34	1.1	28.5	4.9	3.0	14	OFF	130560	306829	
1500	191	409	106	880	426	217	127	119	135	24	27	30	32	24	32	0.9	25.4	4.9	2.2	16	OFF	130692	306853	
1600	186	443	105	895	466	186	126	119	135	24	26	30	32	24	32	1.3	25.6	4.9	1.4	18	OFF	130816	306877	
1700	185	394	105	868	363	212	124	119	135	24	30	32	36	24	34	1.3	29.1	4.8	2.8	20	OFF	130955	306903	
1800	194	357	104	864	350	228	124	119	135	24	30	32	36	24	36	1.3	29.8	4.9	1.4	22	OFF	131082	306929	
1900	196	421	103	896	464	199	122	118	139	24	26	30	32	24	34	2.4	18.6	4.8	1.6	14	ON	131291	306960	BST to 188
2000	191	451	102	905	477	195	120	118	139	24	26	30	32	24	34	1.6	39.5	4.7	1.4	2	OFF	131358	306982	
2100	196	369	101	870	356	235	119	117	139	24	30	34	36	24	36	1.8	20.0	4.8	2.6	4	OFF	131497	307011	
2200	194	443	100	904	476	192	118	116	138	24	26	30	32	24	34	2.6	19.7	4.8	1.8	6	OFF	131634	307036	
2300	192	398	99	881	389	221	118	115	138	24	28	31	34	24	36	1.4	29.8	4.8	3.6	8	OFF	131748	307059	
2400	196	388	98	877	391	213	118	105	136	24	28	31	34	24	36	1.8	34.3	4.8	3.0	12	OFF	131890	307085	

	1200 HRS.	2400 HRS.		1200 HRS.	2400 HRS.
ELECTRIC	1435	1442	ESP LOAD Volts	36	36
TAR 125	300043	300265	ESP LOAD Cur	60	60
WATER	59380	59469	ESP SPARK Rate	0	0
AIR FLOW	557177	562600			
BFW TO JACK	9998391	9999391			
HEAT TRACE	2559	2568			

COAL SCALE CALIBRATION

TEMPERATURES

1 T81 TOP GAS AFTER ESP
2 MIXED GAS, BOILER 1
3 MIXED GAS, BOILER 2
4 T64 BOTTOM GAS
5 T66 MIXED GAS
6 T65 TOP GAS BEFORE ESP
7 T68 BLOWER AIR TEMP
8 T69 ASH FAN
9 T70 BST

GAS ANALYSIS

Time ⇒	23:25
H_2	16.56
$AR \cdot O_2$	–
N_2	47.71
CO	29.7
CH_4	2.033
CO_2	4.005
H_2O	

1/81

(Continued)

TABLE E-1. (Continued)

DULUTH GASIFIER HOURLY LOG

Date 2/25/81	TEMPERATURE °F 1	2	3	4	5	6	7	8	9	PRESSURE " H_2O TOP GAS	BOT GAS	Blast	AIR TO VEN.	Mixed GAS	FLOW RATE Steam FT206	Steam FT208	Air	Water TO Jack	TAR Tank Level	PUMP Status On/Off	Water Jacket FEED	COAL	COMMENTS
100	198	386	97	876	392	214	117	101	136	24	28	31	34	24	36	2.1	35.9	4.8	1.4	12	OFF	132001	307106	Grate A-6.0 BST 134
200	201	386	96	815	393	226	116	104	135	24	28	31	34	24	36	2.4	39.2	4.8	2.4	16	OFF	132136	307133	
300	201	387	95	874	395	218	115	105	185	24	29	32	34	24	36	1.5	28.6	4.8	2.0	18	OFF	132233	307159	
400	193	364	94	867	353	201	115	107	139	24	30	34	36	24	36	2.4	45.0	4.8	2.2	2	OFF	132404	307198	1
500	195	346	92	860	346	226	115	108	134	24	30	34	35	24	36	2.1	40.2	4.8	2.2	6	OFF	132564	307230	BST to 132
600	198	387	91	872	391	207	115	108	133	24	30	33	34	24	36	1.3	26.9	5.0	2.2	10	OFF	132705	307257	
700	196	398	91	879	413	219	114	107	133	24	28	31	32	24	34	1.7	31.7	4.8	2.4	12	OFF	132867	307284	Grate A-5.7 7:35
800	193	413	90	881	428	201	113	107	134	24	28	30	34	25	36	1.9	37.2	4.8	2.8	14	OFF	133015	307308	
900	193	418	89	884	432	217	113	107	134	24	28	31	32	25	34	1.7	30.0	4.8	3.0	14	OFF	133156	307330	
1000	192	421	88	886	433	209	113	107	133	24	28	31	32	24	36	1.5	29.3	4.8	3.2	16	OFF	133316	307357	Grate A-6.0 10:10
1100	191	422	87	888	433	196	114	106	133	24	28	31	32	24	34	1.5	30.8	4.8	3.0	8	ON	133484	307383
1200	189	424	87	891	435	207	116	106	134	24	29	31	32	24	34	1.5	30.2	4.9	2.2	0	OFF	133621	307408	Coal scale counts 2860 12:05
1300	188	424	86	894	435	202	117	106	135	25	28	30	31	24	28	0.1	8.1	3.0	2.8	0	OFF	133796	307436
1400	186	377	86	870	357	210	117	106	134	24	30	34	35	24	37	1.7	33.7	5.0	3.0	0	OFF	133914	307456
1500	188	412	85	894	435	197	117	106	134	26	32	32	32	24	34	1.8	36.0	5.1	2.4	0	OFF	134074	307484
1600	194	385	85	890	406	219	117	105	133	24	28	32	34	24	36	1.7	31.8	5.4	3.0	0	OFF	134230	307511
1700	193	402	84	896	414	207	116	105	133	24	34	32	28	24	36	2.1	37.0	5.2	2.6	4	OFF	134390	307535	Grate A-5.5
1800	195	383	84	890	365	245	114	105	133	24	30	34	38	24	38	2.0	38.1	5.2	3.0	8	OFF	134595	307560	
1900	197	443	84	921	482	202	112	105	133	24	30	32	32	24	34	2.2	45.4	5.3	2.6	10	OFF	134726	307592	
2000	192	470	83	930	495	196	112	104	134	24	29	32	32	24	34	2.0	39.3	5.2	2.6	0	OFF	134888	307617	
2100	193	401	83	902	370	233	112	104	133	24	32	34	36	24	36	1.8	33.5	5.2	2.6	0	OFF	135046	307641	
2200	192	460	83	931	485	187	110	104	133	24	28	32	34	24	34	1.5	31.3	5.3	2.6	0	OFF	135206	307669	Grate A-6.0
2300	187	472	82	939	489	191	109	103	132	24	28	30	32	24	34	1.3	27.1	5.3	2.6	0	OFF	135371	307695	
2400	183	475	82	944	488	190	109	102	133	24	28	30	32	24	34	2.0	37.0	5.3	2.4	0	OFF	135535	307718	

	1200 HRS.	2400 HRS.
ELECTRIC	1447	1454
TAR lb.h	300666	300865
WATER	595443	596884
AIR FLOW	567987	573566
BFW TO JACK.	—	—
HEAT TRACE	2577	2587

	1200 HRS.	2400 HRS.
ESP LOAD Volts	36	36
ESP LOAD Cur	60	60
ESP SPARK Rate	0	0

COAL SCALE CALIBRATION

TEMPERATURES
1 T61 TOP GAS AFTER ESP
2 MIXED GAS, BOILER 1
3 MIXED GAS, BOILER 2
4 T64 BOTTOM GAS
5 T66 MIXED GAS
6 T65 TOP GAS BEFORE ESP
7 T68 BLOWER AIR TEMP.
8 T69 ASH PAN
9 T70 BST

GAS ANALYSIS

Time →	1:50	2:30	3:25	3:30
H_2	15.77	15.48	17.27	12.3
AR-O_2	—	—	—	—
N_2	48.06	48.63	52.93	51.96
CO	30.27	30.04	22.58	30.12
CH_4	1.906	2.014	2.205	1.833
CO_2	4.	3.849	5.267	5.779
H_2O				

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(Continued)

TABLE E-1. (Continued)

DULUTH GASIFIER HOURLY LOG

Date 2/26 81	TEMPERATURE °F 1	2	3	4	5	6	7	8	9	PRESSURE " H_2O TOP GAS	BOT GAS	Blast	AIR TO VEN	Mixed GAS	Steam Jack.	FLOW RATE Steam FT2A	Steam FT2B	L T Vt	Water TO Jack	TAR Tank Level	PUMP Status On/Off	Water Jacket FEED	COAL	COMMENTS
100	178	475	81	948	487	176	109	101	134	24	28	31	32	24	34	2.0	32.2	5.0	2.2	0	OFF	135675	307748	
200	182	403	81	928	392	213	108	94	134	24	31	32	34	24	36	1.3	25.0	5.0	2.2	2	OFF	135824	307774	Grate A-6. Bst 132
300	189	391	81	928	392	215	108	96	133	24	32	34	35	24	36	1.5	31.4	5.2	2.2	6	OFF	135988	307803	
400	195	395	80	932	408	226	107	96	133	24	30	32	34	24	36	1.7	32.8	5.2	2.4	8	OFF	136136	307830	1
500	193	431	80	946	452	206	108	94	133	24	30	32	34	24	36	1.8	21.1	5.2	2.4	10	OFF	136257	307856	
600	189	440	80	952	454	202	109	93	133	24	30	32	34	24	36	1.7	31.0	5.2	2.6	12	OFF	136430	307882	
700	188	443	79	959	454	209	108	94	133	24	29	32	34	24	36	2.0	37.9	5.1	2.6	14	OFF	136620	307913	
800	190	444	79	966	473	200	109	95	134	24	28	32	34	24	35	2.0	36.7	5.1	2.8	18	OFF	136804	307949	
900	191	429	79	950	409	211	108	95	133	24	32	34	36	24	38	1.5	29.2	5.0	2.2	20	OFF	136932	307976	
1000	194	422	78	956	429	227	108	95	132	24	30	33	34	24	36	2.0	34.5	5.2	2.8	23	OFF	137099	308006	
1100	196	455	78	967	476	214	110	95	133	24	29	32	34	24	36	1.9	36.7	5.2	2.4	10	ON	137265	308032	Tar tank at 0 at 11:20
1200	195	465	78	971	481	209	112	95	132	24	28	32	33	24	36	1.8	35.2	5.2	2.8	2	OFF	137467	308062	Coal scale -3475 at 12:00
1300	196	446	77	966	452	227	113	93	134	24	28	32	33	24	35	1.7	32.9	5.2	2.5	4	OFF	137604	308085	
1400	195	482	77	980	504	212	119	91	132	24	28	31	32	24	35	1.7	31.5	5.2	2.6	7	OFF	137772	308110	Grate A-6.5
1500	195	455	77	971	461	208	125	92	133	24	28	32	36	24	36	1.7	30.2	5.3	2.4	10	OFF	137935	308143	
1600	197	454	77	976	490	212	127	94	139	24	28	32	34	24	36	1.8	36.1	5.2	2.6	12	OFF	138112	308177	
1700	191	484	76	979	505	190	128	95	133	24	30	30	34	24	34	1.3	18.6	5.5	2.8	6	ON	138300	308206	Grate A-6.0
1800	191	465	76	976	487	203	128	96	133	24	28	32	34	24	34	1.1	21.8	5.6	2.8	0	OFF	138486	308235	
1900	190	476	76	981	493	200	116	97	133	24	28	32	34	24	34	1.9	35.9	5.2	2.8	2	OFF	138649	308258	
2000	190	447	76	980	463	213	113	98	133	24	28	32	34	24	34	2.1	38.3	5.3	3.0	4	OFF	138829	308287	
2100	191	458	76	986	472	209	112	98	133	24	28	32	34	24	34	1.9	36.1	5.3	2.5	8	OFF	139024	308316	
2200	192	472	76	993	501	219	113	98	133	24	26	32	34	24	34	2.1	36.0	5.3	2.6	10	OFF	139182	308341	
2300	192	501	76	999	524	202	112	99	133	24	26	31	31	24	34	1.4	30.6	5.3	2.4	12	OFF	139344	308371	
2400	190	508	76	998	526	195	112	99	133	24	26	31	32	24	35	1.9	36.5	5.2	2.2	14	OFF	139482	308394	

	1200 HRS.	2400 HRS.
ELECTRIC	1460	1466
TAR	301095	301254
WATER	59762	59822
AIR FLOW	579631	585527
BFW TO JACK.	9998391	9998791
HEAT TRACE	2597	2605

	1200 HRS.	2400 HRS.
ESP LOAD Volts	36	36
ESP LOAD Cur	60	60
ESP SPARK Rate	0	0

COAL SCALE CALIBRATION 10:05 98 lbs/dump

TEMPERATURES
1 T61 TOP GAS AFTER ESP
2 MIXED GAS, BOILER 1
3 MIXED GAS, BOILER 2
4 T64 BOTTOM GAS
5 T66 MIXED GAS
6 T65 TOP GAS BEFORE ESP
7 T68 BLOWER AIR TEMP.
8 T69 ASH PAN
9 T70 BST

GAS ANALYSIS

Time →	9:00	15:20	20:45
H_2	14.68	13.9	14.66
AR-O_2	–	–	–
N_2	50.58	50.09	49.7
CO	27.75	29.13	28.93
CH_4	2.327	1.916	1.931
CO_2	4.66	4.873	4.779
H_2O			

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(Continued)

TABLE E-1. (Continued)

DULUTH GASIFIER HOURLY LOG

Date 2/27 81	TEMPERATURE °F 1	2	3	4	5	6	7	8	9	PRESSURE " H_2O TOP GAS	BOT GAS	Blast	AIR TO VEN	Mixed GAS	Steam Jack	FLOW RATE Steam FT206	Steam FT208	[illegible]	Water TO Jack	TAR Tank Level	PUMP Status On/Off	Water Bucket [illegible] D	COAL	COMMENTS
100	188	510	75	999	524	191	112	99	136	24	30	32	36	25	36	1.8	39.1	5.3	2.6	16	OFF	[illegible]678	308422	Bot 136 :16
200	191	498	75	1002	532	199	112	99	136	24	26	30	32	24	34	2.2	30.0	5.3	2.8	18	OFF	139817	308450	
300	191	487	75	1001	522	205	112	99	135	24	26	30	32	24	34	2.2	41.2	5.3	2.2	20	OFF	139971	308475	Grate A-5.8 3:00
400	191	471	75	993	490	214	112	100	136	24	27	32	32	24	36	2.2	39.1	5.3	2.6	7	ON	140131	308505	
500	191	483	75	991	499	209	111	100	136	24	27	31	32	25	34	2.0	39.1	5.3	2.8	0	OFF	140289	308532	
600	190	480	75	985	462	220	111	99	135	24	28	34	35	24	36	1.9	38.2	5.2	2.6	4	OFF	140450	308557	
700	189	526	74	1017	589	195	110	90	135	24	24	29	30	24	33	2.4	42.0	5.3	2.2	6	OFF	140602	308584	
800	192	440	74	972	398	220	118	91	135	24	31	34	36	24	38	1.5	30.4	5.2	2.8	9	OFF	140765	308612	
900	191	497	75	1001	521	197	114	93	136	24	26	31	32	24	35	2.1	39.0	5.2	2.4	11	OFF	140920	308641	Grate A-6.5 9:40
1000	187	489	75	992	474	192	112	94	135	24	32	34	36	29	38	2.2	39.9	4.9	2.2	14	OFF	141068	308667	Grate A 6.2 10:00
1100	193	422	75	988	444	220	112	96	135	24	28	32	34	24	38	2.4	49.1	5.3	2.4	17	OFF	141214	308700	
1200	196	447	75	986	462	221	113	97	136	24	28	32	34	24	37	2.3	41.2	5.2	0.8	0	OFF	141361	308729	Grate A-6.5 12:15 Coal scale 4084
1300	194	458	75	986	466	210	112	98	136	24	28	33	34	29	36	2.1	40.3	5.2	2.8	2	OFF	141509	308749	Grate A 6.8 13:45
1400	192	454	75	984	464	210	118	99	136	24	28	33	34	24	36	1.6	33.5	5.0	0	5	OFF	141636	308769	Grate A 6.5 2:10
1500	191	428	76	965	401	219	123	101	134	24	32	36	38	24	40	2.3	41.5	5.2	2.2	8	OFF	141787	308788	
1600	193	496	76	996	534	196	116	103	136	24	26	30	32	24	36	1.5	34.9	5.1	1.8	10	OFF	141922	308806	
1700	192	489	76	990	516	205	115	104	136	24	26	32	32	24	34	2.1	39.6	5.1	1.8	12	OFF	142053	308823	
1800	195	484	77	986	543	195	119	105	136	24	26	32	32	24	34	1.7	32.9	5.2	1.8	15	OFF	142191	308842	
1900	190	487	78	979	485	195	116	106	135	24	30	34	36	24	38	2.8	49.4	5.1	2.0	16	OFF	142312	308858	
2000	199	437	78	925	485	225	117	107	136	24	26	32	32	24	36	2.7	44.6	5.4	2.2	6	ON	142452	308877	
2100	195	486	79	981	512	167	117	107	135	24	26	32	32	24	38	2.3	45.7	5.0	2.0	0	OFF	142570	308897	
2200	193	434	79	966	454	200	118	108	135	24	30	32	34	24	36	2.1	33.3	5.2	2.2	0	OFF	142691	308916	
2300	186	447	80	968	458	194	118	109	136	24	28	32	33	24	36	3.1	52.1	5.2	2.0	0	OFF	142846	308935	
2400	186	448	80	966	457	207	118	109	136	24	28	32	34	25	36	2.9	41.9	5.2	1.9	0	OFF	142971	308953	A Ash Bucket Trouble 35 min.

	1200 HRS	2400 HRS
ELECTRIC	1472	1477
TAR 16A	301607	301930
WATER	59917	59943
AIR FLOW	596356	597192
BFW TO JACK	9999391	9999391
HEAT TRACE	2615	2624

	1200 HRS.	2400 HRS.
ESP LOAD Volts	37	37
ESP LOAD Cur	60	60
ESP SPARK Rate	0	0

COAL SCALE CALIBRATION 156 lbs/dump ~ 308723
ON 98 lbs/dump.

TEMPERATURES

1 T61 TOP GAS AFTER ESP
2 MIXED GAS, BOILER 1
3 MIXED GAS, BOILER 2
4 T64 BOTTOM GAS
5 T66 MIXED GAS
6 T65 TOP GAS BEFORE ESP
7 T68 BLOWER AIR TEMP
8 T69 ASH PAN
9 T70 BST

GAS ANALYSIS

Time	11:05	13:10	17:05
H_2	15.35	15.3	14.19
GR-O_2	–	–	–
N_2	48.78	49.02	49.12
CO	27.33	29.02	26.18
CH_4	1.854	1.843	1.324
CO_2	5.502	4.862	8.143
H_2O			

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(Continued)

TABLE E-1. (Continued)

DULUTH GASIFIER HOURLY LOG

Date 2/28 81	TEMPERATURE °F 1	2	3	4	5	6	7	8	9	PRESSURE " H_2O TOP GAS	BOT GAS	Blast	AIR TO VEN	Mixed GAS	Steam Jacket	FLOW RATE Steam FT3/H	Steam FT3/H	Auger TO Lock	TAR Level	PUMP Status On/Off	Water Jacket FLOW	COAL	COMMENTS
100	183	448	81	965	456	193	119	110	137	24	28	31	34	25	36	3.6	61.1	5.3	2.4	0	OFF	143118	309174	
200	183	447	81	963	457	199	118	110	137	24	28	32	34	24	36	2.3	40.9	5.2	1.2	1	OFF	143242	309189	
300	183	448	81	961	458	197	122	110	136	24	28	32	34	24	36	1.8	35.6	5.2	2.8	4	OFF	143383	309008	
400	183	449	82	960	459	197	126	111	130	24	28	34	34	24	36	1.0	21.6	5.5	1.4	6	OFF	143547	309029	
500	182	449	82	957	458	188	122	112	132	24	28	32	34	24	36	1.2	22.2	5.4	4.0	10	OFF	143708	309048	Grate A-6.0 5:10
600	182	448	83	958	458	203	120	113	132	24	28	32	34	–	36	1.4	28.6	5.5	2.0	12	OFF	143867	309066	
700	182	448	84	965	458	197	120	113	132	24	28	32	34	24	36	1.7	32.1	5.3	1.7	15	OFF	144047	309083	Grate A-5.8
800	182	448	84	970	458	184	119	113	136	24	28	32	34	24	36	1.6	32.0	5.2	3.2	18	OFF	144187	309101	Grate A-6. Bst 132
900	185	469	85	993	540	186	118	102	140	24	25	30	31	24	34	2.8	52.4	5.3	4.1	20	OFF	144350	309120	Grate A-6.5 Bst 138
1000	178	550	85	1001	579	163	120	105	139	24	25	29	30	24	34	2.6	46.9	5.0	1.6	21	OFF	144509	309137	
1100	170	497	85	980	465	168	120	108	140	24	28	32	32	24	36	2.1	37.7	5.0	1.8	15	ON	144682	309154	Grate A-6.8 11:00
1200	167	450	86	973	441	174	122	109	137	24	28	32	33	24	36	2.0	37.1	5.2	0	0	OFF	144767	309171	Grate A-6.2 Coal scale - 4515
1300	167	459	86	970	420	181	121	111	142	24	30	34	36	24	38	2.2	37.9	5.0	0	0	OFF	144937	309191	
1400	168	535	86	1000	580	165	121	112	136	24	24	30	30	24	34	2.9	40.3	5.3	5.2	0	OFF	145089	309208	
1500	164	550	86	995	535	163	121	113	135	24	25	30	30	24	32	1.9	35.1	5.3	3.9	0	OFF	145233	309224	
1600	169	405	87	935	357	202	121	113	137	26	32	34	36	24	38	2.4	44.2	5.3	4.2	4	OFF	145419	309240	
1700	171	484	87	967	572	175	117	113	136	24	24	30	32	24	34	2.7	48.1	5.1	3.4	6	OFF	145600	309258	
1800	168	500	87	969	519	175	120	113	141	24	26	30	32	24	34	3.0	53.0	4.7	4.0	10	OFF	145761	309273	
1900	166	502	88	964	516	168	120	114	136	24	26	30	32	24	34	2.1	40.8	5.0	0	12	OFF	145920	309289	
2000	164	502	87	960	505	176	120	115	136	24	26	30	32	24	34	2.0	39.1	5.0	1.0	14	OFF	146060	309304	Bst 132 Cool fire
2100	168	428	88	931	406	199	119	115	132	24	28	32	36	24	36	2.0	36.5	5.2	1.4	16	OFF	146270	309319
2200	175	446	88	945	468	194	116	115	135	24	26	30	36	24	36	2.5	46.3	5.2	1.6	20	OFF	146453	309338
2300	178	441	88	926	398	206	113	115	135	24	29	33	34	24	36	2.3	41.0	5.2	2.8	0	OFF	146597	309352
2400	181	473	88	962	542	188	113	114	135	24	24	30	30	24	33	2.3	43.9	5.2	3.0	0	OFF	146742	309366

	1200 HRS.	2400 HRS.		1200 HRS.	2400 HRS.
ELECTRIC	1483	1489	ESP LOAD Volts	28	36
TAR	302218	302415	ESP LOAD Cur	60	60
WATER	59999	60090	ESP SPARK Rate	0	0
AIR FLOW	603045	608857			
BFW TO JACK.	9999391	9999391			
HEAT TRACE	2633	2641			

COAL SCALE CALIBRATION

TEMPERATURES
1 T81 TOP GAS AFTER ESP
2 MIXED GAS, BOILER
3 MIXED GAS, BOILER
4 T64 BOTTOM GAS
5 T66 MIXED GAS
6 T65 TOP GAS BEFORE ESP
7 T68 BLOWER AIR TEMP
8 T69 ASH PAN
9 T70 BST

GAS ANALYSIS

Time										
H_2										
$H-O_2$										
N_2										
CO										
CH_4										
CO_2										
H_2O										

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(Continued)

TABLE E-1. (Continued)

DULUTH GASIFIER HOURLY LOG

Date 3/1 81	TEMPERATURE °F 1	2	3	4	5	6	7	8	9	PRESSURE " H_2O TOP GAS	BOT GAS	Blast	AIR TO VEN	Mixed GAS	Steam dash	FLOW RATE Steam FT2A	Steam FT2B		Water TO Jack	TAR Tank Level	PUMP Status On/Off	Water Meter D	COAL	COMMENTS
100	179	449	88	931	418	206	113	112	132	24	28	32	34	24	36	2.1	38.3	5.0	2.2	4	OFF	146917	309781	
200	178	480	88	958	505	172	112	111	131	24	26	32	34	24	34	1.8	35.6	5.1	2.6	6	OFF	147083	309899	
300	183	420	88	943	442	205	112	108	132	24	28	32	33	24	36	2.0	31.9	5.3	2.8	8	OFF	147239	309418	
400	182	439	88	942	453	197	112	108	132	24	28	32	33	24	36	2.8	31.6	5.2	3.0	12	OFF	147417	309435	
500	181	442	87	943	453	195	112	107	132	24	28	32	32	24	36	2.0	36.6	5.2	2.6	14	OFF	147586	309452	
600	180	442	87	946	452	201	111	105	132	24	27	32	32	24	34	1.9	36.0	5.2	2.0	12	ON	147757	309468	
700	183	443	81	950	455	207	110	96	131	24	28	32	33	24	34	1.8	35.4	5.2	2.6	3	OFF	147913	309487	
800	184	445	87	955	456	204	115	97	131	24	28	32	33	24	35	1.8	34.8	5.2	2.8	6	OFF	148065	309501	Grate A-6.5
900	184	445	87	955	456	204	121	99	133	24	28	32	33	24	36	1.8	35.0	5.3	2.8	8	OFF	148225	309518	A-6.0
1000	180	498	87	968	580	165	121	102	133	22	28	26	27	24	31	0.9	19.9	4.0	2.0	10	OFF	148370	309535	A-6.8 at 10:50
1100	177	526	86	965	579	157	122	103	132	24	24	26	26	24	30	0.7	17.6	3.5	1.6	12	OFF	148555	309549	A-6.0 at 11:00
1200	171	533	87	970	555	168	124	104	133	24	24	29	29	24	31	1.3	27.9	5.6	1.8	12	OFF	148784	309560	
1300	167	533	87	973	552	161	124	104	132	24	25	28	29	24	32	1.3	25.8	4.7	2.8	15	OFF	148931	309572	
1400	164	533	87	975	551	161	124	104	133	24	25	28	30	24	32	0.9	23.0	4.7	2.5	16	OFF	149085	309586	
1500	161	533	87	980	551	163	128	100	133	24	24	28	30	24	30	0.9	20.2	4.8	2.6	16	OFF	149136	309599	
1600	164	437	88	947	422	180	126	102	133	24	26	30	32	24	32	1.1	21.8	4.9	2.2	10	ON	149311	309615	
1700	168	429	89	948	434	183	126	102	133	24	26	30	34	24	34	0.9	19.7	5.0	2.8	0	OFF	149473	309628	
1800	170	427	89	946	434	189	122	103	133	24	26	30	32	24	34	1.4	25.4	4.4	2.4	0	OFF	149647	309645	
1900	172	426	90	948	435	193	123	103	133	24	26	30	32	24	34	1.7	29.7	4.9	2.4	0	OFF	149794	309657	
2000	174	426	90	947	435	193	120	103	134	24	26	30	32	24	34	1.3	26.0	4.4	2.8	0	OFF	149923	309677	
2100	177	427	90	950	437	200	117	104	133	24	26	30	32	24	34	1.7	32.3	4.7	2.8	0	OFF	150142	309691	
2200	175	485	90	973	517	176	117	104	136	24	26	28	28	25	28	0.8	17.5	3.1	3.0	1	OFF	150308	309707	
2300	170	479	91	938	506	153	115	104	133	24	23	26	26	24	28	0.5	13.6	2.8	2.4	2	OFF	150423	309717	
2400	165	478	91	933	502	152	115	104	132	23	23	26	26	24	28	0.5	12.7	2.8	1.2	3	OFF	150556	309726	

	1200 HRS.	2400 HRS.		1200 HRS.	2400 HRS.
ELECTRIC	1496	1501	ESP LOAD Volts	56	—
TAR	302554	302865	ESP LOAD Cur	60	—
WATER	60156	60262	ESP SPARK Rate	0	—
AIR FLOW	614487	619444	Coal scale	4883	
BFW TO JACK	9999391	9999291			
HEAT TRACE	2651	2659			

COAL SCALE CALIBRATION 153 lbs/hrp 309572 / 4903 } start

TEMPERATURES
1 T61 TOP GAS AFTER ESP
2 MIXED GAS, BOILER
3 MIXED GAS, BOILER
4 T64 BOTTOM GAS
5 T66 MIXED GAS
6 T65 TOP GAS BEFORE ESP
7 T68 BLOWER AIR TEMP
8 T69 ASH PAN
9 T70 BST

GAS ANALYSIS

Time											
H_2											
AR-O_2											
N_2											
CO											
CH_4											
CO_2											
H_2O											

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(Continued)

TABLE E-1. (Continued)

DULUTH GASIFIER HOURLY LOG

Date 3/2	TEMPERATURE °F									PRESSURE " H_2O						FLOW RATE				TAR		Water	COAL	COMMENTS
81	1	2	3	4	5	6	7	8	9	TOP GAS	BOT GAS	Blast	AIR TO VEN.	Mixed GAS	Steam Jam.	Steam FT2A	Steam FT2B	[illegible]	Water TO Jack	Tank Level	PUMP Status On/Off	Jacket FEED		
100	162	433	91	909	407	159	115	104	132	24	24	26	27	24	28	0.4	13.6	2.1	5.4	4	OFF	[illegible]	307756	
200	159	396	91	899	388	165	114	103	134	23	24	26	27	24	30	0.3	12.2	2.8	0	6	OFF	[illegible]	301747	
300	158	385	91	893	385	168	115	104	133	24	24	26	28	24	30	0.1	8.1	2.9	1.8	8	OFF	150887	309756	
400	158	377	92	888	383	171	114	103	134	24	24	28	28	24	30	0.7	16.7	2.8	1.2	10	OFF	151060	309765	T
500	159	373	92	883	381	178	112	103	134	24	24	26	27	24	30	0.3	11.1	2.8	1.6	12	OFF	151122	309774	
600	160	370	92	879	380	172	111	103	132	24	24	27	28	24	28	0.6	14.7	2.8	3.4	14	OFF	151237	309787	
700	159	368	92	870	379	173	110	102	133	24	24	27	28	24	28	0.8	18.3	2.9	3.2	16	OFF	151378	309798	
800	159	366	92	864	378	169	110	102	131	24	24	27	28	24	28	0.3	11.0	2.9	2.4	18	OFF	151425	309810	
900	159	364	92	859	376	173	107	102	134	24	24	27	28	24	28	0.5	11.4	2.9	1.4	18	OFF	151594	309819	
1000	159	363	91	856	377	180	106	101	132	24	24	27	28	24	28	0.3	11.6	2.9	1.2	10	ON	151723	309830	
1100	160	363	91	855	377	181	110	95	133	24	24	27	27	24	28	0.2	8.8	2.9	2.0	0	OFF	151835	309838	11:25 coke in coal scale (309841/51156)
1200	160	401	90	867	440	176	115	93	133	22	24	27	27	24	28	0.5	14.0	2.9	2.6	0	OFF	151948	309846	
1300	160	426	90	871	459	179	119	95	135	24	23	26	26	24	28	0.7	19.0	2.9	1.0	0	OFF	152064	309853	
1400	159	468	90	879	497	181	121	97	132	22	23	26	26	24	27	0.3	19.0	2.9	0.6	0	OFF	152174	309859	
1500	158	484	90	878	503	176	117	98	133	22	24	26	26	24	28	0.4	12.4	2.9	0	1	OFF	152280	309863	G.S. A-6.0
1600	159	482	89	879	503	186	117	99	132	24	22	26	26	24	28	0.4	10.6	2.9	1.0	2	OFF	152387	309869	
1700	160	478	89	878	499	197	117	100	131	24	24	26	26	24	28	0.5	11.4	2.9	2.2	3	OFF	152490	309874	
1800	160	500	89	885	546	182	115	100	131	22	22	26	26	24	26	0.5	11.1	3.0	1.2	3	OFF	152600	309879	
1900	158	538	88	897	609	174	113	100	134	24	22	26	26	24	26	0.7	18.7	2.9	2.0	4	OFF	152717	309884	
2000	156	560	88	897	627	169	112	100	130	22	22	26	26	24	26	0.8	17.5	2.7	2.0	4	OFF	152836	309887	
2100	155	582	88	896	638	163	114	100	134	22	22	26	26	24	28	1.2	23.1	3.0	2.4	4	OFF	152930	309898	
2200	155	590	87	896	639	162	113	101	134	24	22	26	26	24	28	0.8	19.7	3.0	1.0	4	OFF	153026	309896	
2300	157	593	87	868	576	167	111	101	132	24	22	26	26	24	28	1.0	20.6	3.0	1.2	4	OFF	153126	309902	
2400	155	524	86	878	564	181	109	101	131	23	22	26	26	24	28	0.5	18.5	3.0	0	4	OFF	153255	309907	

	1200 HRS.	2400 HRS.		1200 HRS.	2400 HRS.
ELECTRIC	1507	1512	ESP LOAD Volts	36	32
TAR	303073	303073	ESP LOAD Cur	58	60
WATER	60282	60295	ESP SPARK Rate	0	56
AIR FLOW	622528	625627			
BFW TO JACK.	9999391	9999391			
HEAT TRACE	2669	2678			

COAL SCALE CALIBRATION

TEMPERATURES
1 T81 TOP GAS AFTER ESP
2 MIXED GAS, BOILER 1
3 MIXED GAS, BOILER 2
4 T64 BOTTOM GAS
5 T66 MIXED GAS
6 T65 TOP GAS BEFORE ESP
7 T68 BLOWER AIR TEMP.
8 T69 ASH PAN
9 T70 BST

GAS ANALYSIS

Time →											
H_2											
AR-O_2											
N_2											
CO											
CH_4											
CO_2											
H_2O											

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(Continued)

TABLE E-1. (Continued)

DULUTH GASIFIER HOURLY LOG

Date 3/3 81	TEMPERATURE °F 1	2	3	4	5	6	7	8	9	PRESSURE " H_2O TOP GAS	BOT GAS	Blast	AIR TO VEN	Mix of GAS	Steam Jack.	FLOW RATE Steam FT26	Steam FT28		Water TO Jack	TAR Tank Level	PUMP Status On/Off	Water Jacket FEED	COAL	COMMENTS
100	153	540	85	871	567	170	108	101	133	22	22	25	26	24	28	0.7	17.8	3.0	0	4	OFF	153391	309911	
200	151	567	85	884	622	174	107	101	136	22	22	25	26	24	28	0.9	21.9	2.9	1.4	4	OFF	153460	309917	
300	153	521	85	858	594	182	105	101	136	23	23	26	27	24	29	0.9	21.1	3.2	5.0	4	OFF	153576	309922	
400	152	542	85	882	589	187	104	101	136	24	22	26	26	24	28	1.1	22.1	3.2	2.0	5	OFF	153686	309928	
500	153	561	84	887	601	172	102	101	136	24	22	26	26	24	28	0.9	23.2	3.2	2.6	5	OFF	153814	309933	
600	152	567	83	889	603	178	100	100	137	24	23	26	27	25	28	1.0	19.8	3.2	1.8	5	OFF	153925	309938	
700	254	536	84	876	620	167	210	101	210	0	0	0	0	0	0	—	3.5	0	4.0	5	OFF	154033	309943	Not Standby 6:45
800	356	477	103	814	594	157	126	100	203	0	0	0	0	0	0	–	7.0	0	0	5	OFF	154076	309944	
900	282	426	106	726	442	179	97	100	208	0	0	0	0	0	0	–	2.6	0	0	5	OFF	154114	309945	
1000	274	407	106	708	412	181	92	100	207	0	0	0	0	0	0	–	7.5	0	0	5	OFF	154128	309945	
1100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
1200	284	347	103	654	383	180	88	99	208	0	0	0	0	0	0	–	2.0	0	0	5	OFF	154167	309945	
1300	272	328	102	639	370	181	89	98	206	0	0	0	0	0	0	–	1.5	0	0	5	OFF	154183	309945	
1400	258	308	102	623	356	184	92	98	197	0	0	0	0	0	0	–	1.8	0	0	5	OFF	154199	309945	
1500	250	292	101	614	341	186	92	98	201	0	0	0	0	0	0	–	2.9	0	0	5	OFF	154211	309945	
1600	230	273	100	622	315	190	93	98	199	0	0	0	0	0	0	–	1.1	0	0	5	OFF	154228	309945	
1700	227	263	99	580	304	198	90	97	194	0	0	0	0	0	0	–	2.2	0	0	5	OFF	154237	309945	
1800	219	251	98	569	284	207	82	96	191	0	0	0	0	0	0	–	3.3	0	0	5	OFF	154249	309945	
1900	201	237	97	557	265	210	83	94	191	0	0	0	0	0	0	–	4.2	0	0	5	OFF	154262	309945	
2000	197	233	97	534	256	208	84	94	192	0	0	0	0	0	0	–	4.4	0	0	5	OFF	154273	309946	
2100	188	221	96	546	243	209	86	94	191	0	0	0	0	0	0	–	5.1	0	0	5	OFF	154279	309946	
2200	178	213	95	541	230	206	86	93	196	0	0	0	0	0	0	–	3.0	0	0	5	OFF	154288	309948	
2300	177	204	95	529	217	214	80	93	128	0	0	0	0	0	0	–	1.0	0	0	5	OFF	154302	309948	
2400	175	196	95	529	209	196	80	93	183	0	0	0	0	0	0	–	2.0	0	0	5	OFF	154313	309949	

	1200 HRS.	2400 HRS.		1200 HRS.	2400 HRS.
ELECTRIC	1515	1516	ESP LOAD Volts	OFF	OFF
TAR	303073	303073	ESP LOAD Cur	OFF	OFF
WATER	60304	60305	ESP SPARK Rate	OFF	OFF
AIR FLOW	627524	627534			
BFW TO JACK.	9999391	9999391			
HEAT TRACE	2688	2696			

COAL SCALE CALIBRATION 124 lb/dump Start at 309945
Coal Scale Counter 0000 at 309945

TEMPERATURES
1 T61 TOP GAS AFTER ESP
2 MIXED GAS, BOILER 1
3 MIXED GAS, BOILER 2
4 T64 BOTTOM GAS
5 T66 MIXED GAS
6 T65 TOP GAS BEFORE ESP
7 T68 BLOWER AIR TEMP
8 T69 ASH PAN
9 T70 BST

GAS ANALYSIS

Time →											
H_2											
AR-O_2											
N_2											
CO											
CH_4											
CO_2											
H_2O											

1/81

(Continued)

TABLE E-1. (Continued)

DULUTH GASIFIER HOURLY LOG 48

Date 3/5 81

Time	TEMPERATURE °F 1	2	3	4	5	6	7	8	9	PRESSURE " H_2O TOP GAS	BOT GAS	Blast	AIR TO VEN	Mix-ed GAS	Steam Jack.	FLOW RATE Steam FT210	Steam FT208	AIR TO VEN.	Water TO Jack.	TAR Tank Level	PUMP Status On/Off	Water Jacket FEED	COAL	COMMENTS
100	198	124	435	842	449	207	110	86	134	24	24	29	31	25	34	2.7	29.5	6.0	2.6	6	OFF	155977	310098	
200	196	121	448	860	461	196	110	87	134	24	24	29	32	25	34	2.5	46.2	5.8	2.5	6	OFF	156120	310116	A Bucket off Track 2:00 on 2:24
300	193	118	458	878	471	223	109	88	134	24	25	28	31	25	34	2.9	57.0	6.0	2.8	6	OFF	156273	310183	Grate A-6.0 5:15 AM
400	190	115	420	807	393	198	108	89	134	25	28	32	34	25	36	2.4	55.6	5.8	1.8	6	OFF	156418	310252	
500	194	113	424	897	438	206	107	89	133	24	26	30	32	25	34	2.6	45.4	6.0	2.2	6	OFF	156598	310175	Grate A-6.2 5:10 AM
600	190	110	440	919	452	201	107	89	134	24	28	30	32	25	34	2.2	39.4	5.4	2.1	2	OFF	156680	310200	
700	188	108	430	929	449	187	108	90	134	24	26	30	32	25	34	2.6	46.4	5.7	2.2	4	OFF	156813	310224	Grate A-6.0
800	183	106	357	891	341	198	108	91	134	24	30	32	34	25	34	1.9	35.1	4.8	2.2	5	OFF	156933	310248	
900	186	104	334	884	331	208	109	91	135	24	30	32	34	25	34	1.9	34.9	4.8	1.8	6	OFF	157045	310270	
1000	186	102	331	889	332	200	110	91	134	24	29	31	34	25	34	2.0	36.1	4.8	2.2	8	OFF	157160	310301	Bst to 138
1100	183	100	330	889	332	194	113	92	137	24	30	32	34	25	36	2.3	43.3	4.8	1.8	9	OFF	157266	310328	
1200	185	99	333	898	337	209	116	92	137	24	30	32	34	25	36	2.2	46.6	4.8	1.4	11	OFF	157381	310359	
1300	193	98	400	949	456	236	114	92	137	24	26	28	30	25	30	2.3	39.0	4.8	1.6	12	OFF	157483	310377	
1400	180	96	409	942	391	165	114	94	137	24	30	30	34	25	34	2.3	45.2	4.8	1.4	12	OFF	157586	310414	
1500	175	96	369	942	364	177	118	93	138	24	30	32	34	25	36	2.3	43.2	4.8	1.2	12	OFF	157668	310438	
1600	174	95	340	940	339	192	119	94	137	24	32	32	34	25	36	2.0	44.2	5.0	2.0	14	OFF	157794	310470	Bst to 142
1700	176	94	334	938	336	204	116	95	142	24	30	32	34	25	36	2.2	47.6	4.8	1.8	14	OFF	157911	310498	Grate A-6.5
1800	177	93	331	934	333	196	113	94	142	24	30	32	34	25	36	3.3	57.4	4.8	2.0	14	OFF	158044	310537	
1900	180	92	329	925	331	201	111	94	142	24	30	32	34	25	36	3.4	57.4	4.8	2.0	14	OFF	158179	310567	
2000	182	91	327	916	330	205	110	94	141	24	30	30	32	25	36	2.4	41.1	4.6	2.2	14	OFF	158367	310589	Bst to 138
2100	183	90	325	905	328	201	109	93	137	24	28	30	32	25	34	1.9	34.9	4.6	2.4	10	ON	158448	310630	Grate A-6.0
2200	184	89	323	896	326	200	108	90	137	24	28	30	34	25	34	2.1	36.8	4.6	2.2	2	OFF	158577	310656	
2300	187	87	321	885	325	214	107	86	136	24	28	30	34	25	34	2.2	39.7	4.7	2.6	11	OFF	158693	310696	
2400	189	87	322	876	325	198	112	88	137	24	28	31	34	25	34	2.3	40.1	4.6	2.0	14	OFF	158825	310721	

	1200 HRS.	2400 HRS.		1200 HRS.	2400 HRS.
ELECTRIC	1529	1534	ESP LOAD Volts	32	36
TAR	303141	303256	ESP LOAD Cur	-	50
WATER	60661	60803	ESP SPARK Rate	0	0
AIR FLOW	639010	643856			
BFW TO JACK.	9999391	9999391			
HEAT TRACE	2717	2722			

COAL SCALE CALIBRATION

TEMPERATURES
1 T81 TOP GAS AFTER ESP
2 MIXED GAS, BOILER 1
3 MIXED GAS, BOILER 2
4 T64 BOTTOM GAS
5 T66 MIXED GAS
6 T65 TOP GAS BEFORE ESP
7 T68 BLOWER AIR TEMP
8 T69 ASH PAN
9 T70 BST

GAS ANALYSIS

Time →											
H_2											
AR-O_2											
N_2											
CO											
CH_4											
CO_2											
H_2O											

1/81

(Continued)

TABLE E-1. (Continued)

DULUTH GASIFIER HOURLY LOG

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Date 3/6/81	TEMPERATURE °F 1	2	3	4	5	6	7	8	9	PRESSURE " H_2O TOP GAS	BOT GAS	Blast	AIR TO VEN.	Mixed GAS	Steam Jack.	FLOW RATE Steam FT2A	Steam FT2B	AIR TO VEN.	Water TO Jack	TAR Tank Level	PUMP Status On/Off	Water Jacket FEED	COAL	COMMENTS
100	183	86	310	781	305	187	118	89	136	22	22	24	24	24	26	–	1.1	0	1.4	16	OFF	159118	310743	
200	182	86	306	845	310	183	111	92	137	24	28	30	32	24	32	2.0	33.3	4.0	2.6	16	OFF	159215	310757	
300	181	86	307	841	312	205	112	92	140	24	28	31	33	24	34	2.2	37.7	4.6	2.2	16	OFF	159343	310779	
400	184	86	364	870	409	188	113	93	137	24	26	30	32	25	34	2.1	39.9	4.7	3.0	17	OFF	159514	310799	
500	182	86	341	845	328	227	115	93	138	24	28	30	34	25	34	1.8	34.0	4.8	4.0	17	OFF	159702	310827	
600	184	85	344	845	336	223	113	94	140	24	26	30	32	25	34	2.2	40.9	4.8	3.0	14	ON	159865	310843	
700	186	85	343	849	341	219	114	95	137	24	28	30	34	25	36	2.3	40.4	4.8	1.6	14	ON	160061	310867	TURNED TAR PUMP OFF NOT PUMPING 715
800	184	85	429	877	455	194	107	94	137	24	26	28	32	25	34	2.5	48.5	4.9	2.6	4	ON	160250	310887	TURNED TAR PUMP ON 730 OFF 810
900	180	84	461	888	484	185	107	94	137	24	26	30	32	25	34	1.7	39.8	4.8	2.0	3	OFF	160412	310904	
1000	173	84	449	881	450	171	109	95	137	24	26	30	32	25	34	2.2	37.8	4.8	4.5	6	OFF	160640	310925	
1100	172	84	435	879	444	189	109	95	137	22	26	30	32	25	34	2.5	43.0	4.9	1.6	8	OFF	160740	310942	
1200	173	84	430	875	438	188	112	96	136	25	26	30	32	25	34	2.0	38.9	4.9	1.6	10	OFF	160840	310962	–
1300	173	84	430	876	439	192	113	97	137	25	26	30	31	25	34	2.0	36.2	4.9	1.4	12	OFF	161117	310985	
1400	172	84	430	876	439	177	113	97	137	25	26	30	34	25	34	2.5	42.6	4.9	3.2	15	OFF	161267	311006	
1500	170	84	430	876	439	184	113	98	137	25	26	30	33	25	35	2.3	41.1	4.9	2.1	17	OFF	161432	311026	
1600	169	84	429	876	438	176	115	88	137	24	25	30	33	25	35	2.2	38.4	4.9	2.4	18	OFF	161599	311047	
1700	167	84	429	876	438	181	115	85	137	25	27	30	33	25	35	2.3	46.6	4.8	2.6	18	ON	161774	311068	
1800	168	84	429	877	438	158	113	90	137	24	27	30	33	25	35	2.2	39.5	4.9	3.6	6	ON	161944	311090	
1900	168	85	429	877	438	177	111	94	137	22	26	30	32	25	36	2.3	40.9	4.9	3.0	0	OFF	162105	311111	Grate A-5.8 at 7:35
2000	166	84	429	877	437	182	111	96	137	24	26	30	32	25	35	2.6	42.4	4.9	3.2	2	OFF	162281	311132	Grate A-6.0 at 8:35
2100	165	84	429	879	437	171	110	97	137	24	26	30	32	25	35	2.5	43.4	4.9	1.6	4	OFF	162451	311153	
2200	164	84	429	881	438	178	115	98	137	24	26	30	32	25	35	2.6	44.9	4.9	3.6	6	OFF	162651	311173	
2300	165	84	430	885	440	177	111	100	137	24	26	30	32	25	34	2.3	45.4	4.9	3.9	10	OFF	162780	311202	
2400	164	84	431	886	440	170	118	101	137	24	26	30	32	25	34	2.4	42.8	4.9	2.2	12	OFF	162940	311226	Grate A-6.5

	1200 HRS.	2400 HRS.
ELECTRIC	1540	1546
TAR	303825	304136
WATER	60961	61123
AIR FLOW	648850	654430
BFW TO JACK.	9999391	9999391
HEAT TRACE	2728	2734

	1200 HRS.	2400 HRS.
ESP LOAD Volts	25	25
ESP LOAD Cur	50	50
ESP SPARK Rate	0	0

COAL SCALE CALIBRATION

TEMPERATURES

1 TB1 TOP GAS AFTER ESP
2 MIXED GAS, BOILER 1
3 MIXED GAS, BOILER 2
4 T64 BOTTOM GAS
5 T66 MIXED GAS
6 T65 TOP GAS BEFORE ESP
7 T68 BLOWER AIR TEMP
8 T69 ASH PAN
9 T70 BST

GAS ANALYSIS

Time>	8:20	10:00
H_2	13.93	15.48
AR-O_2	–	–
N_2	48.36	57.09
CO	30.2	25.05
CH_4	1.594	1.723
CO_2	5.83	6.426
H_2O		

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TABLE E-2. UMD BOILER HOURLY LOG

DULUTH BOILER HOURLY LOG

DATE February 23, 1981	BOILER NO. 1 DATA					BOILER NO. 2 DATA					BOILER NO. 3 DATA (ON T)			COMMENTS
TIME	GAS PRESS.	STEAM	COND.	GAS	OIL	GAS PRESS.	STEAM	COND.	GAS	OIL	STEAM	CONDENSATE	(OIL) TAR	(ON LINE TIME, OFF LINE TIME, ETC.)
100	20	307288	92427	329814										
200	20	307801	92444	330444										
300	19	308313	92460	331055										
400	19	308778	92477	331625										
500	20	309274	92494	332274										
600	20	309699	92508	332803										
700	19	310225	92525	333461										
800	19	310685	92541	334048										
900	24	310999	92553	334398										
1000	24	311183	92558	334550										
1100	20	311615	92571	335099										
1200	20	311956	92582	335532										
1300	20	312423	92596	336136										
1400	19	312803	92606	336638										
1500	20	313388	92625	337410										
1600	20	313832	92640	337995										
1700	21	314362	92658	338698										
1800	21	314764	92672	339221										
1900	21	315257	92688	339848										
2000	21	317731	92705	340516										
2100	20	316127	92722	341029										
2200	20	316654	92739	341696										
2300	19	317171	92754	342333										
2400	19	317640	92770	342950										

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(Continued)

TABLE E-2. (Continued)

DULUTH BOILER HOURLY LOG

February 24, 1981

TIME	BOILER NO. 1 DATA GAS PRESS	STEAM	COND.	GAS	OIL	BOILER NO. 2 DATA GAS PRESS.	STEAM	COND.	GAS	OIL	BOILER NO. 3 DATA (ON [illegible]) STEAM	CONDENSATE	OIL TAR	COMMENTS (ON LINE TIME, OFF LINE TIME, ETC.)
100	19	318111	92765	343566										
200	19	318596	92803	344177										
300	19	319091	92819	344800										
400	19	319565	92835	345424										
500	19	320060	92852	346034										
600	19	320539	92868	346636										
700	19	321030	92885	347270										
800	19	321498	92901	347863										
900	19	321977	92917	348456										
1000	19	322505	92935	349128										
1100	19	323112	92954	349886										
1200	19	323400	92963	350264										
1300	19	323909	92979	350930										
1400	19	324377	92995	351539										
1500	19	324895	93012	352222										
1600	19	325446	93030	352927										
1700	19	325779	93042	353416										
1800	19	326296	93060	354075										
1900	19	326738	93075	354638										
2000	19	327196	93091	355245										
2100	19	328224	93126	356578										
2200	19	[illegible]	93141	357160										
2300	19	328675	93141	357160										
2400	19	329147	93157	357777										

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(Continued)

TABLE E-2. (Continued)

February 25, 1981

DULUTH BOILER HOURLY LOG

TIME	BOILER NO. 1 DATA GAS PRESS	STEAM	COND.	GAS	OIL	BOILER NO. 2 DATA GAS PRESS.	STEAM	COND.	GAS	O/L	BOILER NO. 3 DATA (OIL fuel) STEAM	CONDENSATE	(OIL) TAR	COMMENTS (ON LINE TIME, OFF LINE TIME, ETC.)
100	19	329653	93174	358411										
200	19	330130	93191	359017										
300	19	330659	93207	359678										
400	19	331117	93223	360276										
500	19	331600	93241	360880										
600	19	332090	93257	361517										
700	19	332600	93275	362192										
800														
900	19	333495	93304	362357										
1000	19	334005	93321	364029										
1100	19	334419	93335	364588										
1200	19	334850	93350	365169										
1300	19	335323	93366	365805										
1400	19	335697	93378	366276										
1500	19	336154	93393	366899										
1600	19	336752	93413	367695										
1700	19	337150	93427	368235										
1800	19	337707	93446	368972										
1900	19	338304	93463	369644										
2000	19	338637	93477	370247										
2100	19	339184	93496	370998										
2200	19	339591	93510	371567										
2300	19	340101	93527	372287										
2400	19	340584	93544	372964										

(Continued)

TABLE E-2. (Continued)

DULUTH BOILER HOURLY LOG

February 26, 1981

TIME	BOILER NO. 1 DATA GAS PRESS.	STEAM	COND.	GAS	OIL	BOILER NO. 2 DATA GAS PRESS.	STEAM	COND.	GAS	OIL	BOILER NO. 3 DATA (ON ...) STEAM	CONDENSATE	(OIL) TAR	COMMENTS (ON LINE TIME, OFF LINE TIME, ETC.)
100	19	341034	93559	373608										
200	19	341547	93576	374300										
300	19	343049	93593	374974										
400	19	342562	93611	375666										
500	19	343047	93625	376345										
600	19	343530	93645	376970										
700	19	344022	93662	377644										
800	19	344526	93680	378356										
900	19	344987	93695	378966										
1000	19	345136	93715	379732										
1100	19	345586	93738	380313										
1200	19	346033	93758	381205										
1300	19	346564	93776	381791										
1400	19	347069	93798	382340										
1500	19	347982	93797	383112										
1600	19	348431	93813	383748										
1700	19	348861	93829	384429										
1800	19	349345	93846	385172										
1900	19	349866	93861	385818										
2000	19	350324	93877	386463										
2100	19	350809	93899	387159										
2200	19	351307	93911	387878										
2300	19	351740	93924	388557										
2400	19	352204	93944	389325										

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(Continued)

TABLE E-2. (Continued)

Feb 27. 1981

DULUTH BOILER HOURLY LOG

TIME	BOILER NO. 1 DATA: GAS PRESS.	STEAM	COND.	GAS	OIL	BOILER NO. 2 DATA: GAS PRESS.	STEAM	COND.	GAS	OIL	BOILER NO. 3 DATA (ON LINE): STEAM	CONDENSATE	(OIL) TAR	COMMENTS (ON LINE TIME, OFF LINE TIME, ETC.)
100	19	352659	93957	389875										
200	19	353187	93975	390657										
300	19	353915	93989	391211										
400	19	354074	94005	391903										
500	19	354514	94020	392532										
600	19	355056	94038	393328										
700	19	355217	94054	394015										
800	19	355974	94069	394696										
900	19	356114	94084	395315										
1000	19	356841	94102	396026										
1100	19	357300	94119	396736										
1200	19	358015	94133	397463										
1300	19	358776	94148	398201										
1400	19	359315	94169	398870										
1500	19	359328	94183	399460										
1600	19	359869	94202	400322										
1700	19	360343	94218	400891										
1800	19	360514	94234	401549										
1900	19	361316	94251	402361										
2000	19	361746	94266	402831										
2100	19	362253	94283	403544										
2200	18	362700	94301	404030										
2300	18	363344	94321	405023										
2400	18	363779	94336	405646										

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(Continued)

TABLE E-2. (Continued)

DULUTH BOILER HOURLY LOG

Feb. 28 1981

TIME	BOILER NO. 1 DATA GAS PRESS	STEAM	COND.	GAS	OIL	BOILER NO. 2 DATA GAS PRESS	STEAM	COND.	GAS	OIL	BOILER NO. 3 DATA (ON ...) STEAM	CONDENSATE	(OIL) TAR	COMMENTS (ON LINE TIME, OFF LINE TIME, ETC.)
100	18	364268	94952	406276										
200	18	364732	94368	406926										
300														
400	18	365253 ~~408534~~	94403	408395										
500	18	366235	94419	409007										
600	18	366763	94937	409773										
700	15	367266	94452	410364										
800	18	367699	94468	411079										
900	18	368313	94481	411927										
1000	15	368736	94503	412546										
1100	15	369177	94531	413211										
1200	18	369647	94536	413895										
1300	15	370299	94555	414515										
1400	18	370577	94565	415134										
1500	18	371010	94580	415960										
1600	18	371568	94598	416780										
1700	18	371965	94612	417363										
1800	18	372387	94634	417993										
1900	18	372889	94643	418749										
2000	18	373300	94651	419360										
2100	18	373780	94678	420084										
2200	18	374222	94687	420706										
2300	18	374715	94704	421372										
2400	18	375157	94719	422002										

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(Continued)

TABLE E-2. (Continued)

DULUTH BOILER HOURLY LOG

28 MAR. 1981 TIME	BOILER NO. 1 DATA GAS PRESS.	STEAM	COND.	GAS	OIL	BOILER NO. 2 DATA GAS PRESS.	STEAM	COND.	GAS	OIL	BOILER NO. 3 DATA (ON [illegible]) STEAM	CONDENSATE	(OIL) TAR	COMMENTS (ON LINE TIME, OFF LINE TIME, ETC.)
100	18	375688	94727	422782										
200	18	376078	94750	423345										
300	18	376542	94766	424003										
400	18	377016	94782	424700										
500	18	377501	94798	425406										
600	18	377935	94813	426034										
700	18	378429	94830	426746										
800	18	378926	94847	427455										
900	18	379359	94861	428090										
1000	20	379841	94878	428772										9:50A cut back on [illegible]
1100	20	380151	94888	429187										10:45A [illegible] load ([illegible])
1200	19	380553	94901	429786										
1300	19	380951	94913	430386										
1400	19	381353	94921	430991										
1500	19	381870	94944	431746										
1600	19	381164	94953	432176										
1700	19	38[illegible]79	94967	432770										
1800	19	382872	94982	433672										
1900	19	383994	94997	434018										
2000	21	383918	95011	434596										
2100	19	384412	95028	435267										11:00 Reduce load [illegible] Required by [illegible] Personnel.
2200	21	384837	95042	435862										
2300	24	385147	95052	436226										
2400	24	385436	95061	436581										

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(Continued)

TABLE E-2. (Continued)

MAR 2 1981	DULUTH BOILER HOURLY LOG													
	BOILER NO. 1 DATA					BOILER NO. 2 DATA					BOILER NO. 3 DATA (ON ...)			COMMENTS
TIME	GAS PRESS	STEAM	COND.	GAS	OIL	GAS PRESS.	STEAM	COND.	GAS	OIL	STEAM	CONDENSATE	(OIL) TAR	(ON LINE TIME, OFF LINE TIME, ETC.)
100	24	385752	95070	436965										
200	24	386047	95079	437325										
300	22	386346	95087	437685										
400	22	386636	95096	438034										
500	22	386971	95106	438438										
600	22	387299	95115	438836										
700	22	387591	95124	439201										
800	22	387911	95133	439575										
900	22	388290	95144	440267									1483180	Start burning tar 8 [illegible]
1000	22	388476	95150	440288							549620	43215	1483530	
1100	22	388802	95159	440694							550064	43243	1483780	
1200	22	389134	95169	441108							550466	43267	1484020	
1300	22	389410	95177	441475							550807	43298	1484210	
1400	22	389644	95184	441808							551120	43306	1484390	
1500	22	389930	95192	442204							551506	43330	1484620	
1600	22	390185	95199	442561							551851	43350	1484810	
1700	22	390434	95206	442907							552176	43370	1485000	
1800	22	390724	95215	443333							552570	43394	1485220	
1900	22	390970	95222	443712							552923	43415	1485430	
2000	22	391152	95227	444009							553247	43435	1485610	
2100	22	391440	95236	444511							553719	43464	1485870	
2200	22	391627	95241	444836							554025	43482	1486050	
2300	22	391875	95248	445265							554423	43507	1486280	
2400	22	392070	95254	445577							554731	43525	1486460	

(Continued)

TABLE E-2. (Continued)

DULUTH BOILER HOURLY LOG

DATE MAR 3 1981

TIME	BOILER NO. 1 DATA					BOILER NO. 2 DATA					BOILER NO. 3 DATA (ON TAR)			COMMENTS
	GAS PRESS.	STEAM	COND.	GAS	OIL	GAS PRESS.	STEAM	COND.	GAS	OIL	STEAM	CONDENSATE	(OIL) TAR	(ON LINE TIME, OFF LINE TIME, ETC.)
100	22	392511	95261	445955							555107	43548	1486680	
200	22	392552	95268	446388							555490	43571	1486910	
300	22	392931	95276	446825							555866	43594	1487120	
400	22	393109	95284	447267							556232	43616	1487340	
500	22	393380	95292	447701							556606	43639	1487560	
600	22	393655	95300	448156							557009	43664	1487800	
700		394095	95310	448475							557359	43682	1487990	Out gas #1 boiler 6:[illegible]
800											557759	43710	1488250	
900											558193	43732	1488510	
1000											558697	43767	1488810	
1100											559056	43788	1489020	
1200											559402	43804	1489220	
1300											560103	43836	1489480	
1400											562255	43861	1489740	
1500											560699	43887	1490000	
1600											561101	43910	1490250	
1700											561505	43933	1490500	
1800											561920	43951	1490090	76 A gal. tar
1900											562325	43971	1490890	Put 3 cart sulfur - [illegible] After trying, [illegible]
2000											562552	43994	1491110	
2100	#1 Gt	[illegible] ON STANDBY												
2200														
2300														
2400														

TABLE E-3. GAS STREAMS FLOW RATES

	grams/ second	Nm^3/min. (25°C, 1atm)	SCF/min. (60°F, 1atm)	Molecular Weight (dry)	Moisture Content (%)
Combined Product Gas	930	57	2000	23.8	9.6
Cleaned Top Product Gas	560	33	1200	24.4	19.2
Raw Top Product Gas	530	33	1100	23.9	19.3
Top Product Gas	540	33	1100	24.2	19.2
Cleaned Bottom Product Gas	460	26	890	25.8	4.2
Raw Bottom Product Gas	670	38	1300	26.2	4.5
Bottom Product Gas	560	32	1100	26.0	4.4
Product Gas Boilers Combustion Emissions	5600	280	9400	29.8	9.2
Boiler No. 3 Firing ESP Oils Combustion Emissions	5200	250	8700	30.1	7.0
Boiler No. 3 Firing Natural Gas Combustion Emissions	3700	180	6200	29.8	15.0

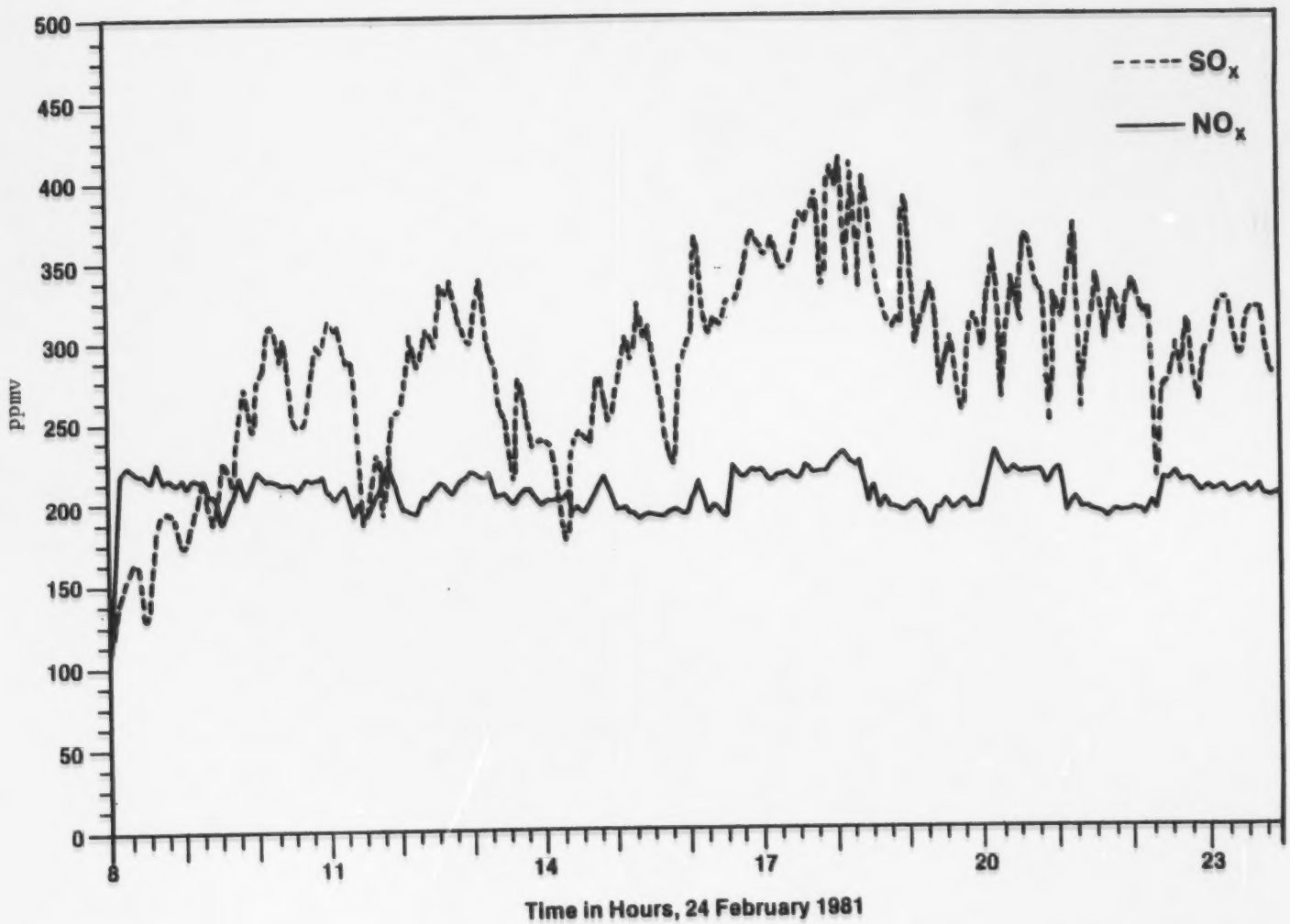

Figure E-1. NO_x and SO_x emissions from product gas boilers.

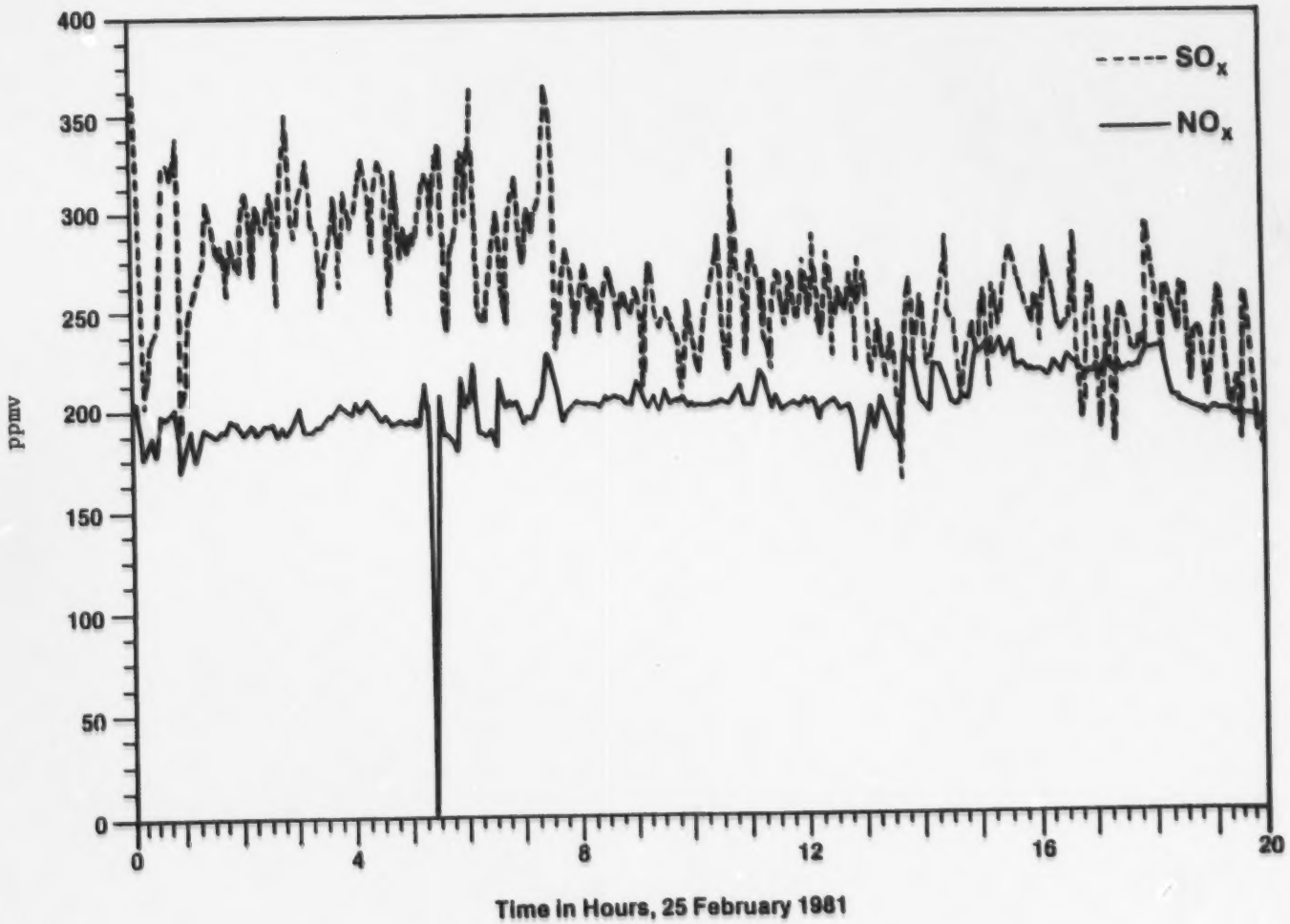

Figure E-2. NO_x and SO_x emissions from product gas boilers.

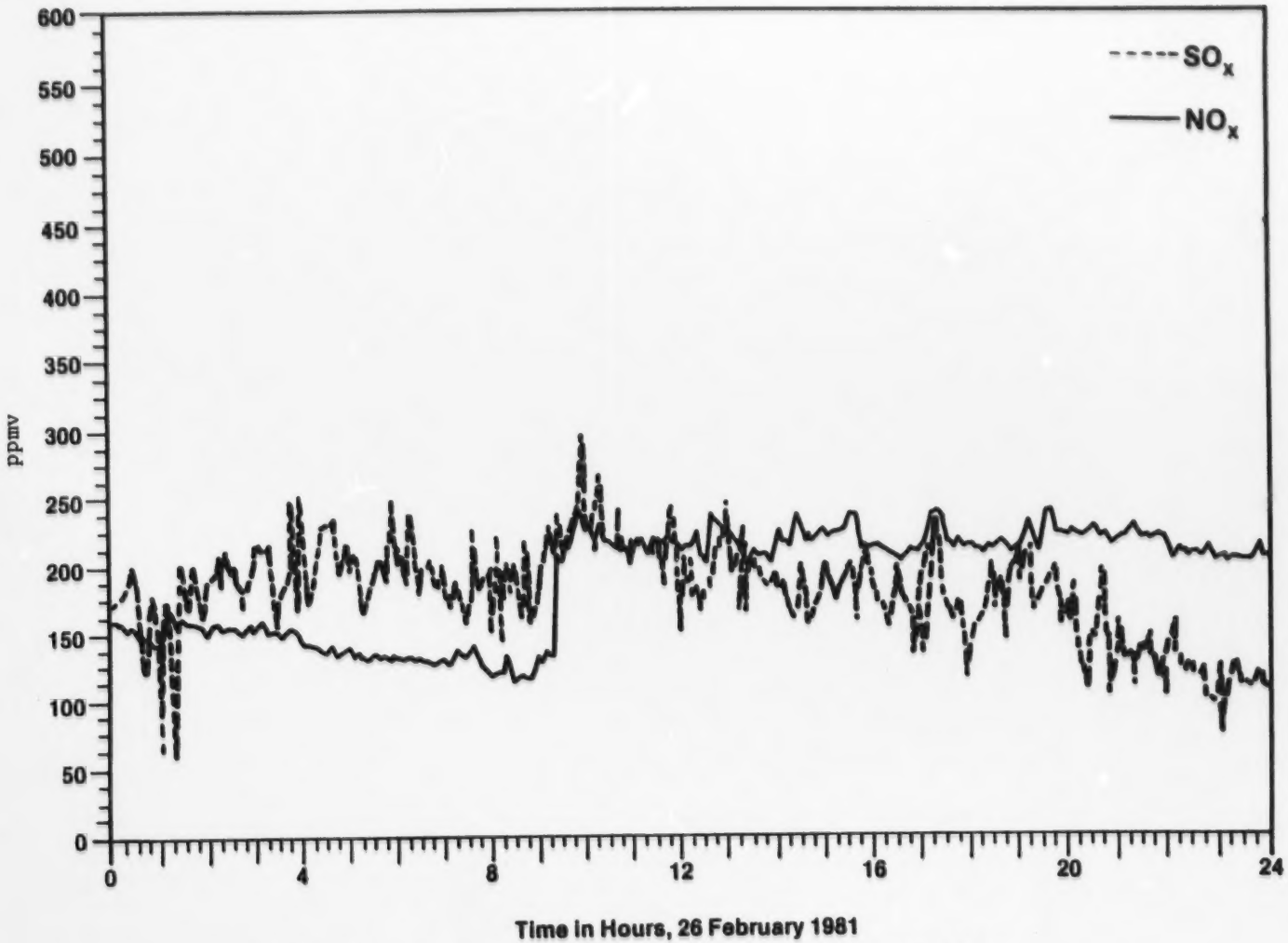

Figure E-3. NO_x and SO_x emissions from product gas boilers.

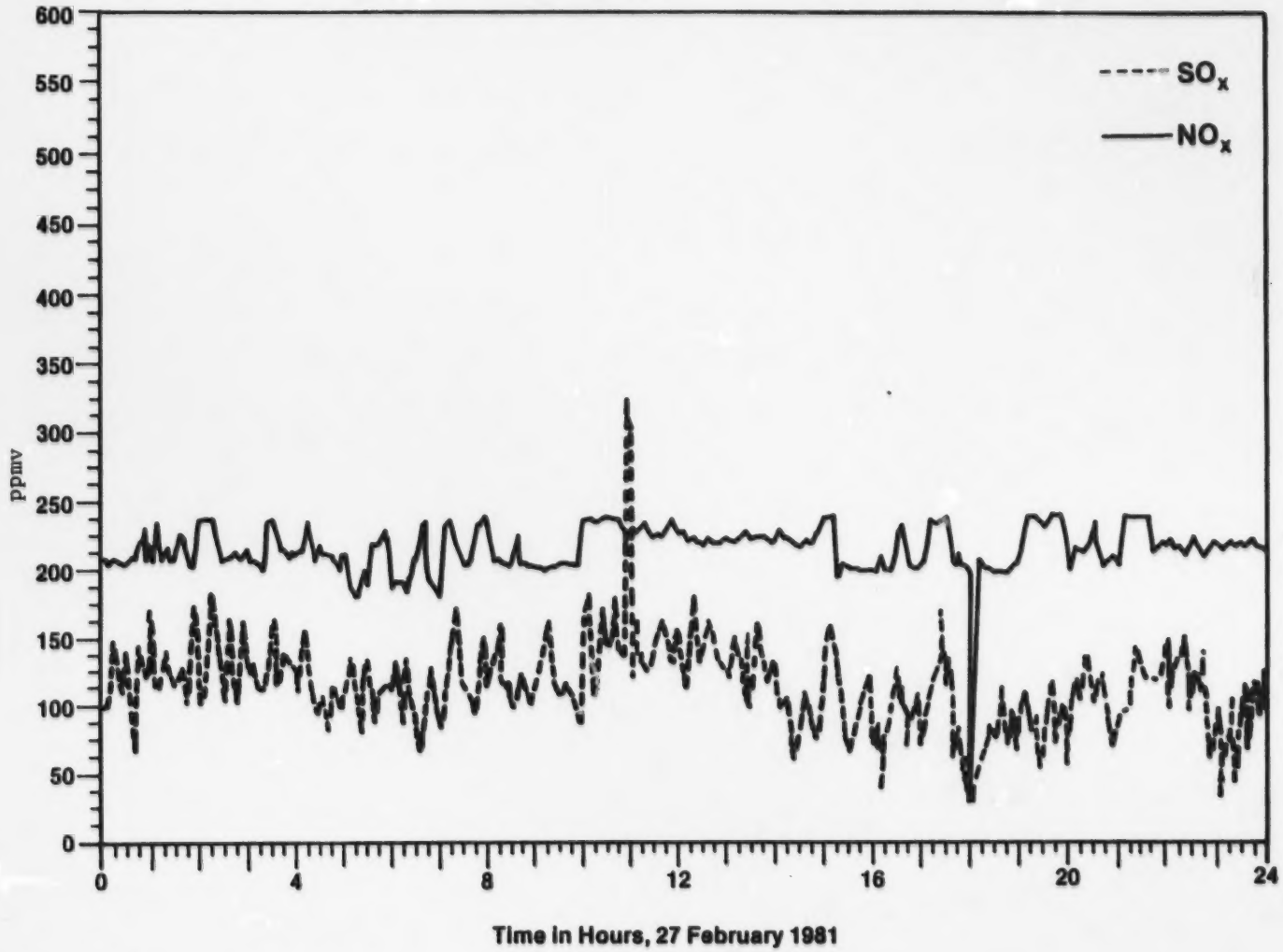

Figure E-4. NO_x and SO_x emissions from product gas boilers.

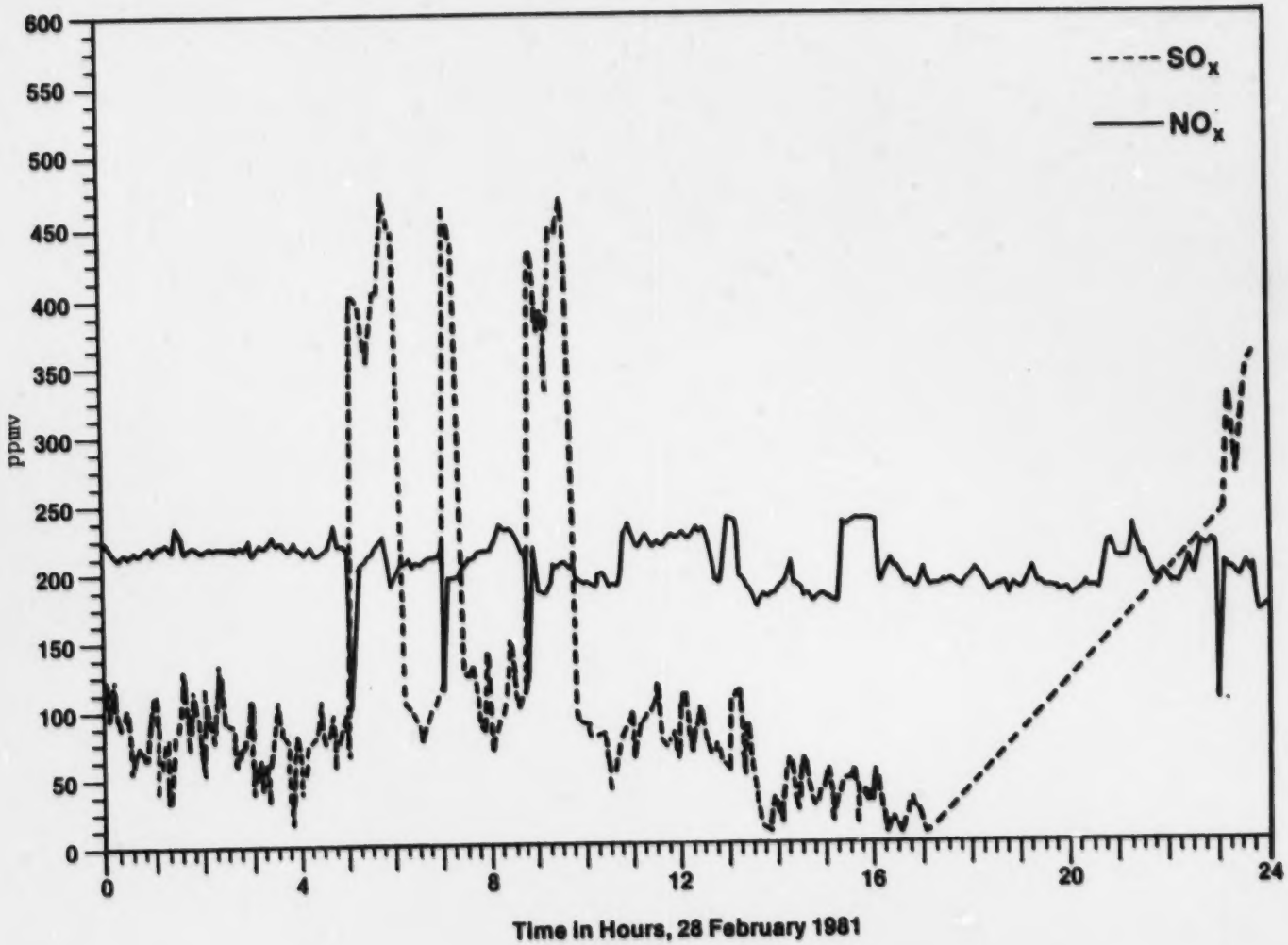

Figure E-5. NO_x and SO_x emissions from product gas boilers.

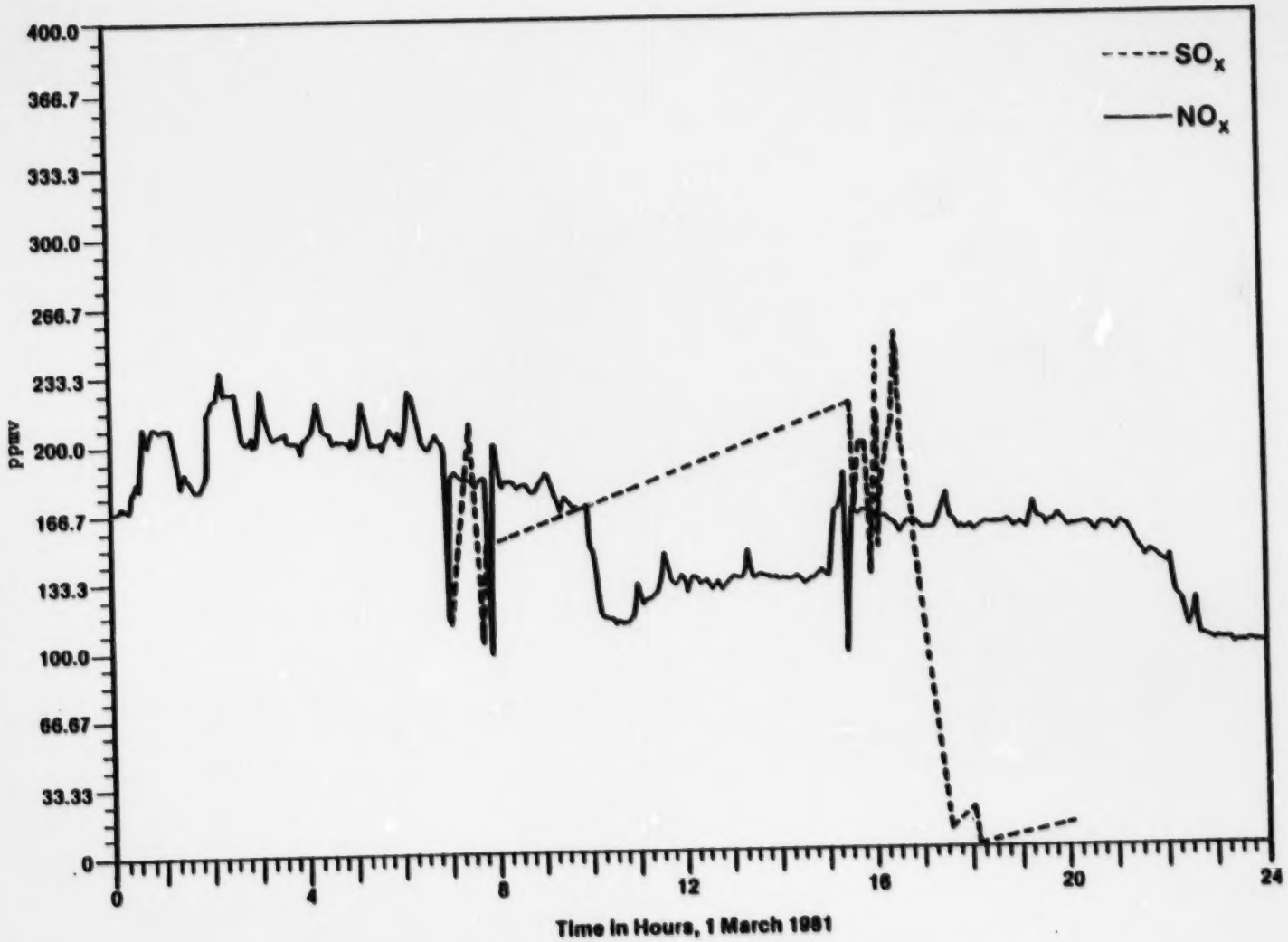

Figure E-6. NO_x and SO_x emissions from product gas boilers.

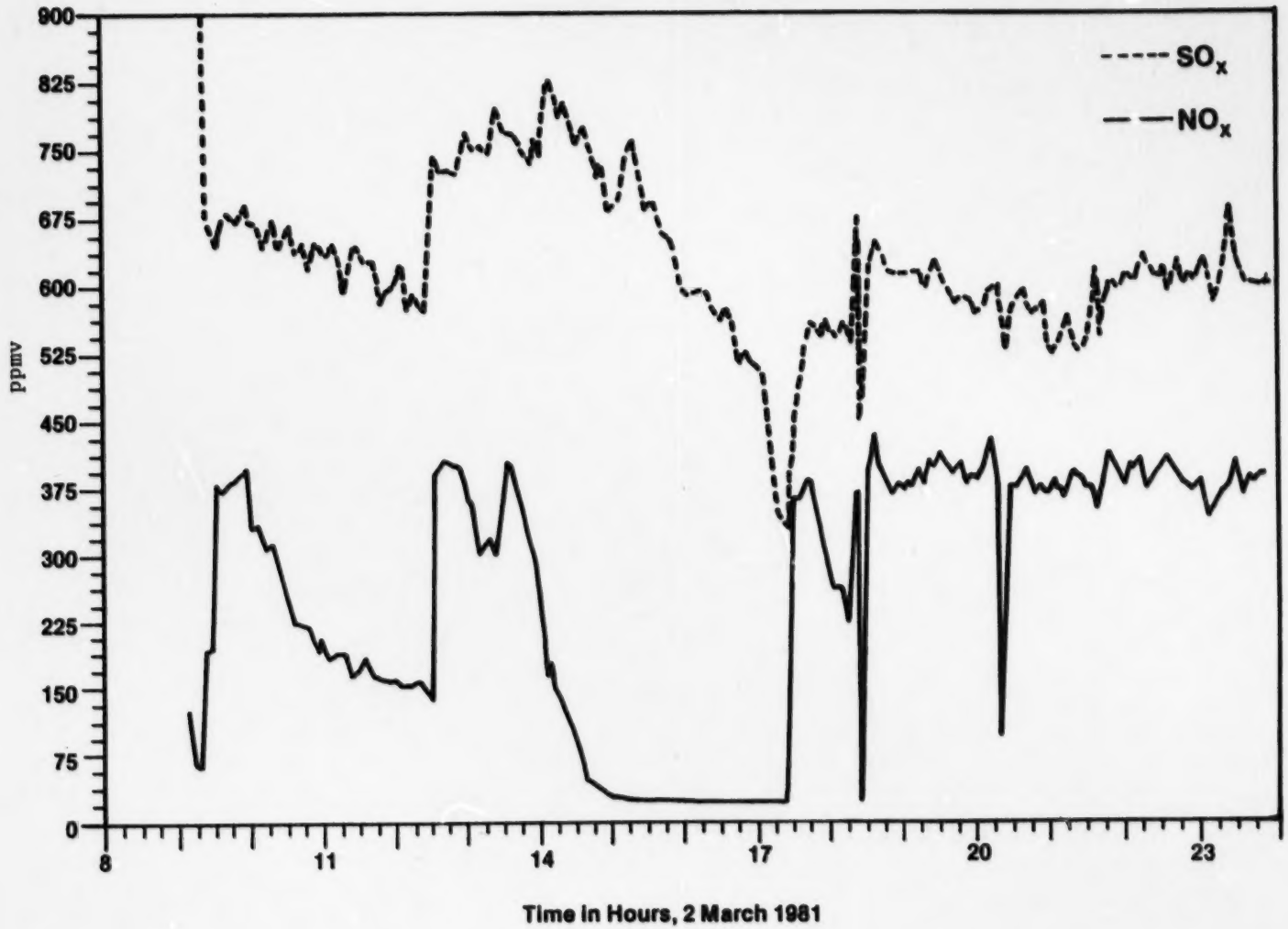

Figure E-7. NO_x and SO_x emissions from product gas boilers.

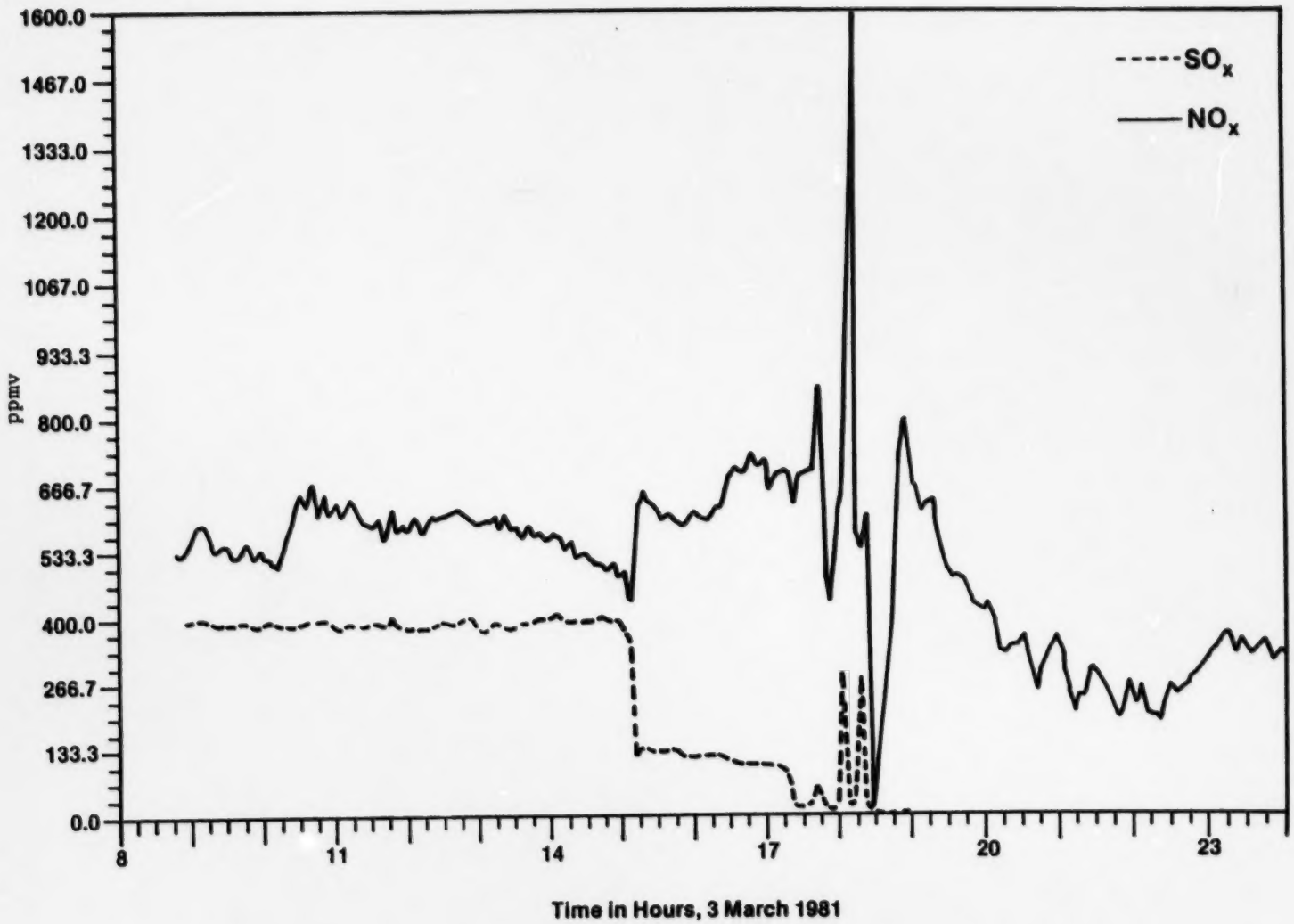

Figure E-8. NO_x and SO_x emissions from product gas boilers.